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ESSAYS

ON

THE PHILOSOPHY AND ART

OF

LAND-DRAINAGE.

BY JOSIAH PARKES, C.E.,

HONORARY MEMBER OF THE ROYAL AGRICULTURAL SOCIETY OF ENGLAND.

LONDON:
LONGMAN, BROWN, GREEN, AND LONGMANS,
PATERNOSTER ROW.

1848.

> " Popular belief is often founded on correct observation, and sound practice is not unfrequently in advance of science. It also not uncommonly happens that the evidence of practical truths is received with scepticism because we are unable immediately to 'interpret nature,' and frame a satisfactory theory or explanation of the origin of particular phenomena. Hence the discovery of causes is of the highest importance to the arts, and a correct theory of any action so rapidly accelerates, extends, and perfects sound practice, that we cannot too highly prize its possession."—*The Author*, p. 21.

London: Printed by William Clowes and Sons, Stamford Street.

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ESSAY I.

ON

THE INFLUENCE OF WATER

ON THE

TEMPERATURE OF SOILS.

ALSO,

ON THE QUANTITY OF RAIN WATER,

AND ITS

DISCHARGE BY DRAINS.

BY JOSIAH PARKES, ESQ.,
CONSULTING ENGINEER TO THE ROYAL AGRICULTURAL SOCIETY OF ENGLAND.

1844.

FROM THE
JOURNAL OF THE ROYAL AGRICULTURAL SOCIETY OF ENGLAND, 1844,
VOL. V., PART I.

INFLUENCE OF WATER

ON THE

TEMPERATURE OF SOILS,

&c. &c.

INTRODUCTION.

TO PH. PUSEY, ESQ., M.P.

DEAR SIR,—I have at length endeavoured to comply with your wish to receive an account of the few experiments I made, some years since, on the temperature of a particular soil; of the motives which induced me to enter on them; and of the practical utility to which an extended series of such experiments may be expected to lead.

The importance of an inquiry into the physical properties of different soils, and particularly into the causes affecting their state of heat and moisture, has been glanced at by various philosophers and agriculturists; but I am not aware that a systematic pursuit of it has yet engaged the attention of any British experimentalist. Mr. Handley, in his letter to Earl Spencer, which preceded the formation of the Society, has cited certain phenomena with which, it must be admitted, we are very insufficiently acquainted; and he has pointed out, as still remaining among the mysteries of nature, the action of several of her most energetic agents. He observes, —"The experimentalist might be usefully engaged in determining the temperature of the earth at its surface, and to the depths accessible to the cultivator; the influences exerted by heat, light, and air; how far they penetrate into the soil, and at what point seeds cease to germinate; the effects of different culture in promoting the absorption and retention of caloric; the extent and operation of capillary attraction;—points which, hitherto much disregarded, evidently act an important part in hastening and perfecting the maturity of plants, and the study of which appears to be at least as interesting to mankind as those scientific labours which have been exercised with so much zeal to deduce the intensity of a central fire from experiments showing the increasing temperature of the body of the globe the deeper we bore into it." *

I have no pretension either to the ability or the knowledge to fill up these *vacua* in the science of agriculture; it may appear, even from the following imperfect observations, that the gaps are still wider than those above recited; yet I would express my conviction that there exist no obstacles which should discourage the possessor of land and leisure from entering on this unexplored field of investigation; but, on the contrary, there is reason to anticipate that his labours would be made in a land of promise, and that they would be abundantly repaid.

Previously to detailing my own and other very limited experiments on the temperature of soils, it may be well to consider some of the operations of the husbandman, their intent, and the manner in which the heat and moisture of a soil may be affected by them. The two principal agricultural processes, upon which, perhaps, the fertility of land depends as much as on the artificial aids now so scientifically and beneficially applied to it, are drainage and pulverization.† These mechanical operations are practically known to be indispensable to the full development of the natural powers of soils, as well as to the profitable employment of the numerous and costly stimulants latterly introduced into agriculture; and it is my present object to show that the temperature of soil is materially influenced by the perfection of these processes; and that each particular soil is benefited by them, according to the degree in which it may require to be artificially drained or worked. You have forcibly remarked that "all who are acquainted with improved husbandry are now agreed that, on wet land, thorough-draining is to a farm what a foundation is to a house."* Water, indeed, forms an essential element in soil, but there may be as much difference, in respect of fertility, between a *wet* soil and a *moist* one—though they be identical in other respects—as between a swamp and a garden. By drainage and pulverization the proper degree of humidity is to be attained in most soils; for, though it is wisely ordained that we cannot control the precipitation of rain, we do possess the power of regulating, within certain limits, the quantity of moisture to be retained by the earth, and of adjusting it, as it were, to the quality of the soil, and to the requirements of vegetation.

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* Letter to Earl Spencer on the Formation of a National Agricultural Institution. 1838.

† The term *drainage* is here used in an extensive sense, not confining it to the construction of artificial conduits for water, nor to its application on those soils only which are reputed as *wet*. The mere acts of digging, ploughing, and working soils reputed as *dry*, do, in reality, effect drainage by opening channels for the descent of water from the superficial to the lower strata.

SECTION I.

Physical Action of Water.

The consideration of the well-known effect of drainage on soils surcharged with water naturally leads to an examination of the causes of the change produced in them by so simple an operation. A soil perfectly dry, or one perfectly wet, *i e.* constantly drenched with water, would be nearly alike sterile; and we may conceive that some certain proportions may exist between the amounts of heat and moisture adapted, so far as their agency is concerned, for bringing a given soil, in a given latitude or situation, to its maximum state of fertility. The researches of different philosophers have elucidated the laws which pertain to water, in its several states, as a fluid, a solid, and a vapour or steam. There is, probably, no natural substance which has been investigated with greater success, and there is perhaps no other substance which performs more numerous or more important parts in its action on soil, and in the economy of vegetable life, than water. In its chemical relations to the solid, saline, and gaseous constituents of soil there may still be something to discover; but its physical properties as regards heat, its operation as a solvent, and its mechanical laws, are sufficiently ascertained to enable us to understand, and explain satisfactorily, the various benefits that are afforded to wet soils by drainage.

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* Journal, vol. iii. p. 170.

If a soil be saturated with water, the nobler classes of plants cannot flourish; they vegetate more or less imperfectly, until the quantity of water be so diminished as to suit their habits. The reduction of the excess of water to the due proportion can only be effected, naturally, by its gradual evaporation, *i. e.* by its conversion into vapour; and its transition from the fluid to the aëriform state is accompanied by the absorption of so large a quantity of heat from the soil in contact with it, that it may be convenient to consider its action in this respect first, and to endeavour to appreciate its amount.

When water is set over a fire in an open vessel, its temperature, as indicated by the thermometer, cannot be made by any force of fire to exceed 212°, under the mean atmospheric pressure of about 30 inches of mercury. The temperature of the water then becomes stationary, and the heat of the fire is afterwards expended in converting the water into steam or vapour. The temperature of the steam continues to be precisely that of the water, and it has been found that it requires about six times as much heat to boil off any given volume of water as would raise the temperature of that volume from 50° to 212° Hence it is concluded that the difference, or $162 \times 6 = 972$ degrees of heat, have passed through the water, and entered into the composition of every atom of steam. Steam, therefore, has a much greater capacity for heat than water. These continual accessions of heat are absorbed by the steam in the act of its formation, and become what is termed *latent*, *i. e.* insensible to the thermometer, which, plunged in the steam, marks only the same temperature as that of the water from which it was generated, viz., 212°. This latter is termed the *sensible* or *thermometric* heat of the steam. That the whole of the heat thus expended in changing water from its fluid into its gaseous state has entered into the steam, is proved, conversely, by condensing a given weight of steam in water, when it is found that a pound of steam will raise about 6 lbs. of water from 50° to the boiling-point.

Water is vaporizable at all temperatures when exposed to the atmosphere. Its expulsion from the earth does even, under certain circumstances, continue when the atmosphere is replete with moisture, or at what is termed the dew-point. And it is most important to observe that, at however low a temperature the water in the soil, or that of the atmosphere incumbent on it may be, at which vapour is formed and expelled, the same amount of heat is carried off by a *given weight* of vapour as if it had been generated in the open vessel over the fire above referred to, or in the close boiler of a high-pressure steam-engine. A practical confirmation of the truth of this law has been obtained by evaporating water under widely different pressures, when it appeared that the same weight of fuel (or measure of heat) was consumed in converting equal bulks of water into steam at all those different pressures. It is ascertained that it requires as much heat as 2 or 3 oz. of coal will produce to convert 1 lb. of water into vapour: it is, therefore, evident what an enormous quantity of heat must be taken from the soil in cases where water is allowed to remain stagnant upon it till it evaporates.

As heat is generally considered to be an imponderable body, we are without the means of ascertaining directly, by weight or measure, the quantity of heat absorbed from soil by the evaporation of water. The following illustration of it will, however, be familiar enough to the mind of the engineer, and will also, I think, enable intelligent farmers to form an idea of its immense amount.

If we suppose the rain falling on the surface of an acre of land in the year to be 30 inches in perpendicular depth, it would amount to 108,900 cubic feet = 3038 tons; which, spread over a twelvemonth, gives an average of 298 cubic feet = 8⅓ tons, or 18,647 lbs. per diem. This weight of water would require, for its diurnal evaporation—supposing it were all carried off by that means—the combustion of about 24 cwt. of coals, as ordinarily used under a steam-boiler, or 1 CWT. PER HOUR PER ACRE throughout the year! We thus obtain some idea of the abstraction of heat from land under the circumstances of perfect aqueous repletion and stagnation, and there are too many soils approaching to them. We may also imagine the depression of the terrestrial temperature consequent on the abstraction of so much heat from the mass of the soil—a depression which must ever be in proportion to the excess of water present in the soil, over and above the due complement required for the supply of vegetation. Soils in that state must necessarily be very cold in the spring months, and much colder at the time of the commencement of vegetation, and throughout the summer, than well-drained or naturally drier lands. If we knew the capacity for heat of any given soil, and the weight of water mixed with it in excess over the proper complement necessary for vegetation, it would be easy to determine, very nearly, the depression of temperature caused by its evaporation. We know that the heat of a pound of water in its gaseous state, that is, as steam, would raise the temperature of about 1000 lbs. of water one degree; so that if the specific heats of the solid and fluid bodies were alike, the evaporation of a pound of water would keep down the temperature of 1000 lbs. of earth one degree; of 500 lbs. two degrees; and so on.

Secondly; excess of humidity obstructs the absorption of heat by the solid matter of the soil. Water, in a quiescent state, is one of the worst conductors of heat with which we are acquainted. If it be warmed on the surface—and it derives, when mixed with soil, nearly all its heat from the sun's rays—water transmits little or no heat downwards.

If a mass of water be heated from below, the whole quickly attains an uniform temperature by reason of the motion excited amongst its particles. The lowest stratum, when heated, becomes of less specific gravity than that resting upon it, and the heavier superincumbent portions descend and push that which has been warmed upwards. In this manner rapid circulation is induced. If, on the contrary, it be heated from above, *i. e.* on the surface, the film of warmed water floats on the top, by virtue of its superior levity, and no heat is conveyed below; there is no circulation from above downwards. Much of the heat of the sun's rays is, therefore, prevented by excess of water from entering into, and being transmitted through, the mass of the soil.

Thirdly; water is a powerful radiator of heat, *i. e.* it cools quickly. All bodies, whether fluid or solid, possess peculiar powers of emitting or radiating heat, and water was esteemed by the late Professor Leslie—in which opinion he has been joined by other philosophers—to stand at the head of radiating substances.

The phenomena of the production of cold by radiation and evaporation are elegantly exemplified by the well-known experiment of exposing water, warm enough to give off visible vapour, in one saucer, and an equal bulk of water drawn from a well in another saucer. The former, on a sharp frosty morning, will be found to exhibit ice the soonest.* The cooling powers of evaporation and radiation combined, and of radiation chiefly, or solely, are represented in this experiment by the order of congelation in the two vessels in time; but the difference in the quantity of heat emitted from each of them is immense, as appears from what is stated above with reference to the constituent heat of vapour.

Fourthly; as the temperature of water diminishes during the night, or in the day-time, according to the varying conditions of the atmosphere, by radiating its heat to the heavens, its specific gravity increases; and the superficial stratum, which is first cooled, immediately descends by reason of its augmented density. This film of cooled and heavier water is as quickly replaced by relatively warmer and lighter portions, which become cooled in turn, and successively sink. Water, therefore, though a non-conductor of heat downwards when warmed on the surface, becomes a ready vehicle of cold in that direction when cooled on its surface; and this cooling process may even continue, under fitting circumstances, until the whole of a given mass is reduced to the low temperature of about 42°, at which point water attains its maximum density. The further descent of cold through this process would then cease; but the refrigeration occasioned by it must affect all soils, to a greater or less degree, which hold water in excess, *i. e.* when in a state of stagnancy near to the surface. Those soils only can be exempt from this chilling influence which are not naturally retentive of water, or which are artificially and deeply drained.

Thus, excess of water conduces to the production of *cold* in soil, by means of several independent, vigorous, and ever-active properties.

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* Boiling water thrown on the ground will freeze sooner than cold water.

On the other hand, when a soil is naturally so porous, or is brought into such condition by art (viz. by drainage), that rain-water can sink down into the earth, it becomes a carrier, an alert purveyor, instead of a robber of *heat;* and tends to raise, permanently, the temperature of the mass of useful soil; and this more particularly and beneficially during the vegetative season. Rain-water, at that time, conveys downwards the more elevated superficial heat of the soil, and imparts it to the subsoil in its course to the drains; it leaves the soil in a fit state to receive fresh doses of rain, dew, and air, and in a better condition to absorb and retain heat, at the same time that it promotes, in other ways, its fertility and productiveness; but a consideration of the chemical effects attributable to the continual circulation and renewal of water and air is foreign to the present discussion.

In order to render the change of water perfect, and its action uniform throughout a field, all drains should be deeper than the active or worked soil, and covered. If drains are open, much of the rain precipitated on the surface necessarily passes into them before it has permeated the whole mass; consequently, it carries off with it heat, which would have been usefully employed in warming the lower strata; and it may, at the same time, remove fertilizing matter. If drains are not deeper than the worked bed, water remains below in a stagnant state, which must chill the roots of plants, and diminish the temperature of the superincumbent mass.

Gardeners and florists are well aware of the injurious influence of water when supplied constantly to the pan instead of to the surface of the soil in the flower-pot; and *bottom* water, as it is frequently and very appropriately called, produces the same ill effects when stagnating too near the surface of the great agricultural bed.

Superficial drainage is comparatively of little value, and is, perhaps, exemplified in its worst practical form by land tortured on the ridge and furrow system. When land is permanently cultivated in high ridges, the crowns can obtain but partial benefit from the action of rain. The gradation from the comparative dryness and warmth of the summit, to the suffocating wetness and coldness of the furrows, is commonly evidenced by the state of the crops grown on land so disposed.*

SECTION II.

Physical Properties of Earthy Matter.

The influence of drainage and pulverization on the temperature of soils is, necessarily, dependent on the habits and constitution of the solid as well as of the fluid matter composing or mixed with the soil. The variety of substances which enter into its composition; their peculiar structure; the state of their division or size of their particles; their colour; their respective powers of absorbing, conducting, and radiating heat; their bibulousness—all these properties conspire to the determination of the temperature of a given soil: and these properties are irrespective of latitude or locality. Chemists have informed us of the specific heat, of the absorbing and radiating energy of various earths, and of many soluble and insoluble bodies, when submitted separately to investigation; but we possess little or no knowledge of these relations when such various substances are blended together, as we find them to exist in the agricultural bed. It is there we should seek for information; it is on the mass of the soil itself practical men should experiment, to ascertain the facts in question. Nevertheless, the labours of the laboratory are not to be rejected; it is by their agency, chiefly, that we have acquired our complete knowledge of the phenomena of water; and investigations conducted in the closet may materially aid the experimentalist in the field. I have extracted the following opinions and researches from the works of two distinguished British philosophers, as they relate to the affinity to moisture and heat of many bodies found in soil, and illustrate this division of the subject.

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* It would be curious—but, possibly, more curious than useful—to learn the origin of this remarkable artificial configuration given to land, which is, I fancy, peculiar to England and to particular counties. One would think that this system must have been invented previous to the discovery that water would find its way into cut drains; or, the inventor may have considered rain as his greatest enemy, and that he ought to prevent its entrance into the soil and get rid of it as soon as possible. I once put the question, as to the utility of this process, to a few farmers in Cheshire with whom I was in company. Their notion was that an undulating, being greater than a plane surface, more stuff would grow on it. It stood to reason that such must be the case! This was debated at great length, I contending it was a fallacy. On a division I was left in a minority of one.

Professor Leslie, who added largely to our knowledge of the phenomena of heat and moisture, thus introduces the mention of his experiments on the hygrometric powers of some of the earths, which, for the sake of brevity and perspicuity, are collected in the following table:—

> "Absorbent substances, besides assimilating to their essence a portion of the liquid which touches them, are likewise disposed to attract, though with various energy, the humidity of the atmosphere. The more solid, as well as the softer, materials exert this power, and which is exactly analogous to that of the concentrated acids and the deliquescent salts. In their several affinities to moisture the earthy bodies discover the most essential differences of constitution. To examine these properties, let the substance be dried thoroughly, and almost roasted before a strong fire, and introduced immediately into a phial with a close stopper; the powder having undergone that sort of preparation is, at any time afterwards, thrown partially into a very large wide-shaped bottle, and shut up till it has attracted its share of humidity from the confined air; and a delicate hygrometer being now let into the bottle indicates the measure of the effect produced by absorption."

	Degrees of Moisture absorbed from Air at about 60°.
Clay, very highly torrefied	8
Silica, ditto	19
Whinstone, ditto	23
Carbonate of strontites	23
Carbonate of barytes	32
Clay, strongly roasted	35
Silica, soaked in water, and dried after high torrefaction	35
Silica, in its natural state	40
Carbonate of lime	70
Shelly sea-sand	70
Carbonate of magnesia	75
Sea-sand, from a sheep-walk	78
Whinstone, in its natural state	80
Alumina	84
Pipeclay	85
Sea-sand, cultivated	85
Whinstone, in a crumbling state	86
Ditto, reduced to mould	92
Garden mould	95

Leslie remarks that "the absorbent power of the earths depends as much on their mechanical condition as on the species of matter of which they are composed. Whatever tends to harden them diminishes the measure of their effect; and hence, apparently, the reason why the action of fire impairs their desiccating quality." *

Useful as is this contribution to the philosophy of soils, it must be deemed very remarkable that the ingenious author altogether omitted to investigate the relation of the same substances to the absorption of heat as well as moisture. The importance of ascertaining these double relations did not, however, escape the sagacity of Davy, who preceded Leslie in this research, and whose remarks are so pertinent, and possess such intrinsic worth, that I trust the citation of them will not be thought tedious:—

"Many soils are popularly distinguished as *cold;* and the distinction, though at first view it may appear to be founded on prejudice, is really just.

"Some soils are much more heated by the rays of the sun, all other circumstances being equal, than others; and soils brought to the same degree of heat cool in different times, *i. e.* some cool much faster than others.

"This property has been little attended to in a philosophical point of view, yet it is of the highest importance in agriculture. In general, soils that consist principally of a stiff white clay are heated with difficulty; and, being usually very moist, they retain their heat only for a short time. *Chalks* are similar in one respect —that they are difficult to heat; but, being drier, they retain their heat longer, less being consumed in causing the evaporation of their moisture.

"A black soil, containing much soft vegetable matter, is most heated by the sun and air; and the coloured soils, and the soils containing much carbonaceous matter, or ferruginous matter, exposed under equal circumstances to the sun, acquire a much higher temperature than pale-coloured soils.

"When soils are perfectly dry, those that most rapidly become heated by the solar rays likewie cool most rapidly, their power of losing heat by radiation being the greatest; but I have ascertained by experiment, that the darkest-coloured dry soil (that which contains abundance of animal or vegetable matter—substances which most facilitate the diminution of temperature), when heated to the same degree, provided it be within the common limits of the effect of solar heat, will cool more slowly than a wet pale soil entirely composed of earthy matter.

"I found that a rich black mould, which contained one-fourth of the vegetable matter, had its temperature increased in an hour from 65° to 88° by exposure to sunshine, whilst a chalk soil was heated only to 69° under the same circumstances. But the mould removed into the shade, where the temperature was 62°, lost, in half an hour, 15°; whereas the chalk, under the same circumstances, had lost only 4°.

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* Leslie, on Heat and Moisture, p. 96, 1818.

" A brown fertile soil and a cold barren clay were each artificially heated to 88°, having been previously dried. They were then exposed in a temperature of 57°. In half an hour the dark soil was found to have lost 9° of heat; the clay had lost only 6°. An equal portion of the clay containing moisture, after being heated to 88°, was exposed in a temperature of 55°. In less than a quarter of an hour it was found to have gained the temperature of the room.* The soils, in all these experiments, were placed in small tin-plate trays, two inches square, and half an inch in depth; and the temperature ascertained by a delicate thermometer.

" Nothing can be more evident than that the genial heat of the soil, particularly in spring, must be of the highest importance to the rising plant; and when the leaves are fully developed, the ground is shaded, and any injurious influence, which in the summer might be expected from too great a heat, entirely prevented: so that the temperature of the surface, when bare, and exposed to the rays of the sun, affords at least one indication of the degrees of its fertility; and the thermometer may be sometimes a useful instrument to the purchaser or improver of lands, &c."—*Agricultural Chemistry*.

The chapter containing these experiments and opinions of Sir Humphry Davy will supply many other useful hints for the guidance of the experimentalist in his inquiry into the causes of the varying temperature of soils. I will select only one other short extract from the well-known lectures of this eminent man, as it records information touching the affinity of some particular soils to moisture, the fertility and rent-value of which he quotes as being pretty nearly in the ratio of their hygrometric powers.† The soils were first dried at a temperature of 212°, and then exposed to air saturated with moisture at 62°:—

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* A remarkable confirmation of what has been before stated of the chilling effect of evaporation.—J. P.

† Schübler has criticised this opinion of Davy's (Journal, vol. i. p. 197). He observes, "The assumption of Davy, that this capacity of absorption possessed by a soil was to be received as a *conclusive* proof of its fertility, is liable, therefore, to many exceptions; and, if applied without modification, might easily mislead." Excepting in one instance, Schübler's experiments appear to confirm, very closely, Davy's observation,—" I have compared the absorbent powers of many soils with respect to atmospheric moisture, and I have always found it greatest in the most fertile soils: so that it affords *one* method of judging of the productiveness of land." I have not noticed that Davy has anywhere spoken of it as a *conclusive* method. Davy, Leslie, and Schübler all agree on the fact of garden-

	Gain of Moisture in an hour. Grains.
" 1000 grains of a celebrated soil from Ormistown, in East Lothian	18
1000 grains of a very fertile soil from the banks of the river Parrett, in Somersetshire . . .	16
1000 grains of a soil from Mersea, in Essex .	13
1000 grains of a fine sand from Essex . .	11
1000 grains of a coarse sand	8
1000 grains of a soil from Bagshot Heath . .	3 "

In reflecting on the results of these isolated experiments, and on the conclusions drawn from the consideration of some single property of soils (whether they be just or otherwise), the philosophic mind cannot fail to perceive how infinitely more valuable such experiments would be to the agriculturist were they combined with direct indications of the actual constitution of the same soils in their natural state, and under culture, as regards their attraction for heat and moisture. May it not be reasonably expected that a well-conducted series of experiments on these phenomena would illustrate some of the causes which conduce to render certain soils in a higher latitude more productive than others in a more southern one? Might they not serve to detect fallacies in reasoning or practice—to show, possibly, that effects have been attributed to wrong causes—and to unfold to our perception a clearer and more correct knowledge of the workings of nature?

From the foregoing review of the physical properties of soils in relation to heat and moisture, and of the action of water in warming or cooling them, it will be seen that a very remarkable difference obtains between the properties of the fluid and solid bodies. It appears that water absorbs heat rapidly, but can only convey it downwards by itself descending into the earth; that the heat which it receives from the solar rays is again projected into the atmosphere

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mould being the most absorbent of all soils. Davy specially excepted the case of a pure clay; and Schübler also instances that earth as an exception to the general law deduced by both philosophers, that the fertility of soils is pretty much in the ratio of their powers of absorbing and retaining moisture. Schübler has made a step in advance of Davy, by his elaborate experiments tending to establish the fact that moisture in earth is a preparation for its absorption of oxygen, and consequently that the attraction of soils for moisture is a property of first-rate importance to agriculture.

by radiation, and in combination with vapour, when it remains stagnant on or near to the surface; whereas, solid substances impart the heat which they absorb to all surrounding matter, in all directions (though with different degrees of rapidity), as well as to the atmosphere. There is yet another important effect arising from the radiating force of solids to notice. As the sun verges towards the horizon, the superficial layer of the earth becomes colder than the atmosphere, causing the precipitation of dew, which the affinity of earthy matters to moisture enables them to absorb, and thereby to recruit in part, by night, the loss of moisture which has taken place during the day. Water also radiates heat powerfully, but it does not attract moisture to itself, except under very peculiar and rare circumstances: hence, again, the advantage of drainage. These important processes, viz. the absorption of moisture and the radiation of heat, will be carried on with more or less energy in proportion to the inherent qualities of a soil, to its state of mechanical preparation, and to the proper adjustment of its supply of water.

SECTION III.

Cause and Physical Action of Dew.

The quantity of moisture attracted from the atmosphere, in the form of dew, is unknown; but the cause, and many of the laws, of its formation, deposition, and physical action, have been disclosed to us by the talents and labours of Dr. Wells, whose experiments and Essay on this subject stand almost unrivalled in the records of science as examples of skilful investigation and profound induction.* Previously to the conclusive experiments of this admirable philosopher, the formation of dew was held to be the *cause* of the cold observed with it, and he originally entertained the same opinion.

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* The original 'Essay on Dew,' which appeared in 1814, is very scarce, but is republished in the 'Works of Dr. Wells' (1818), containing a memoir of his life, written by himself.

A distinguished living philosopher thus writes of this theory, after making a concise but searching analysis of it:—"We have purposely selected this theory of dew, first developed by the late Dr. Wells, as one of the most beautiful specimens of inductive experimental inquiry lying within a moderate compass. It is not possible, in so brief a space, to do it justice; but we earnestly recommend his work (a short and entertaining one) for perusal to the student of natural philosophy, as a model with which he will do well to become familiar."—*Discourse on the Study of Natural Philosophy*, by Sir J. F. Herschel, 1832, p. 163.

> "But," he observes, "I began to see reason, not long after my regular course of experiments commenced, to doubt its truth, as I found that bodies would sometimes become colder than the air, without being dewed; and that, when dew was formed, if different times were compared, its quantity, and the degree of cold which appeared with it, were very far from being always in the same proportion to each other. The frequent recurrence of such observations at length converted the doubt of the justness of my ancient opinion into a conviction of its error, and at the same time occasioned me to conclude that dew is the production of a preceding cold in the substances on which it appears."

Further—

> "that the cold which produces dew is itself produced by the radiation of heat from those bodies upon which dew is deposited."

Thus it was discovered that an *effect* had heretofore been mistaken for a *cause;* and the explanation of the various phenomena connected with the subject, afforded by this theory, has since remained unchallenged, and is admitted to be incontrovertible.

Besides the determination of the immediate cause of dew, Dr. Wells ascertained, among other phenomena affecting the temperature of soils, that the attraction of substances for water is not exactly proportional to their radiating energy; and that—

> "the formation of dew not only does not produce cold, but, like every precipitation of water from the atmosphere, produces heat."

As the earth becomes colder than the atmosphere on dewy nights by reason of its radiating energy, and as the moisture suspended in the latter possesses the atmospheric temperature, dew, with respect to the surface of the earth, is warm. Were it not that this antagonist warming process counteracts, on cloudless and serene nights, the rapid escape of heat from the earth by radiation, it is probable that the temperature of the soil would be depressed, during the sun's absence, by a greater amount than it is elevated during its presence; and that the extremes of heat and cold, or the vicissitudes of temperature, during 24 hours, might be so great as to destroy vegetable life in the summer season.

The least experienced observer may easily satisfy himself of the superior cold of the earth's surface on clear nights, relatively to that of the atmosphere. Hoar-frost, which is frozen dew, frequently forms on grass when the thermometer in the air indicates a temperature some degrees higher than the freezing-point; a phenomenon showing that the earth, or the leaves of plants, were colder than the atmosphere, and below the freezing-point, when the deposition took place. In Bengal, ice is (or was) procured artificially, on a large scale, and for profit, by exposing water to the sky in porous earthen pans placed in shallow pits. The difference of temperature between the air and the water, at the time of its congelation, has often been observed, on clear serene nights, to amount to 14°, and even 16°. The air near the ground must then have had a temperature of about 46° or 48°.

The genius of Davy would appear to have almost divined the mystery of dew-making, even before the complete revelation of its true and only cause by Dr. Wells, as may be gathered from the following profound remark:—

> "The power of soils to absorb water from air is much connected with fertility. When this power is great, the plant is supplied with moisture in dry seasons; and the effect of evaporation in the day is counteracted by the absorption of aqueous vapour from the atmosphere, by the *interior* parts of the soil during the day, and by both the *exterior* and *interior* during the night."—*Agricultural Chemistry.*

If a soil be sufficiently permeable to air, and not saturated with water, it is in a state to receive accessions of moisture from the atmosphere, which is a constant and inexhaustible vehicle of humidity; and if the temperature of a sufficiently porous subsoil be at or below the dew-point, as will frequently be the case, during some portion of the day, in the summer season, the process of depositing dew will take place in "the interior parts of the soil during the day," at the same time that the exterior, or surface of the ground, may be projecting both heat and moisture into the atmosphere. This process is evidently dependent on the relative temperatures and degrees of aqueous repletion of the air and subsoil at a given time; and independent of the hygrometric power of the latter, which is, however, a potent auxiliary to the acquisition and retention of atmospheric moisture by soil, particularly in its interior parts. Thus, it is apparent that the acquisition of moisture by soils in the form of dew is not limited to the period of the night only, nor to the surface of the earth; and it has been shown that the precipitation of dew cannot take place without the communication of heat to the recipient substance: hence the importance of sufficient pulverization to permit access and change of air to the interior parts of soil. One of the most beneficial effects of drainage may be also safely presumed to arise from its facilitating the access, and change, of air to the very bottom of the bed; as, in proportion to the escape of water, so will be the entrance of the air, which will, *pari passu*, occupy the place vacated by the water.

Every observant farmer must have remarked that the amount of dew precipitated during the same night varies greatly on different soils in fallow, and still more on the leaves of different plants. Well-pulverised soils attract much more dew than those which are close and compact, as the radiation of heat is effected from many more points in highly comminuted than plane surfaces. Sands appear to be powerful attractors, and in some countries to depend altogether on the nightly deposition of moisture for the support of vegetation. An extreme example of the derivation of the aqueous element from dew alone, and of its highly fertilising qualities, is afforded by the fact that, on the sandy plains of Chili, rain is scarcely ever known to fall; yet that soil, which under other circumstances would be sterile, is maintained in a productive state by the active forces of radiation and absorption. The temperature of the soil is moderated during the period of the sun's action by the large amount of heat carried off combined with vapour; whilst the exhausted humidity is replaced by dew, deposited during the resplendent nights of that tropical region. Instances are also on record of the flourishing growth of trees in Africa on sandy districts, never refreshed by rain nor springs, nor by artificial supplies of water: whilst soils of another nature, in the same latitude, and not far distant, require irrigation to enable them to sustain vegetable life.

It is to the copious dews of our own country that we have in great measure to attribute the productiveness of the meadows bordering streams and rivers. The atmosphere, in the neighbourhood of currents of water, becomes more highly charged with aqueous vapour than that of the uplands; and as the air transports and disperses this moisture over the adjoining fields, it is condensed and precipitated during the night by the process discovered and illustrated by Dr. Wells.* The finely-divided and filamentous structure of the grasses renders them, in addition to their demand for aqueous nutriment, peculiarly suitable for culture in these localities. It is worthy of notice that the leaves of different plants appear to act in somewhat different ways as to their mode of receiving and disposing of dew. A blade of grass is sometimes spangled over with dew-drops, but it usually becomes wetted throughout its whole surface by the running together of the drops, and thus conducts the water to the earth in minute streamlets; whereas, the leaves of the clover, cabbage, nasturtium, and many other plants, will be found to collect it in distinct globules, which may be rolled about on the leaf without appearing to moisten it. These drops, in fact, do not touch the leaf, but rest and roll upon a pillow of air interposed between them and the substance of the leaf. I have not unfrequently procured a teacup full of dew, early in the morning, from the leaves of a single cabbage-plant; and, on very translucent nights, I have seen, whilst watching this elegant and interesting process, the tender clover-leaf bend beneath the weight of its crystal load, discharge it on the ground, and immediately begin to accumulate another globule. In the course of three or four hours I have observed as many collections and discharges of dew by the same leaf. The gradual diminution of the size of these drops of water, by evaporation, as the sun exerts its influence, has often struck me to be the means provided by nature for preparing plants to sustain his increasingly-ardent rays without injury; and it is generally after nights of copious deposition of dew that the mornings are the brightest, and the sun's heat the most powerful. Cup-formed and horizontal leaves and flowers seem to retain all, or nearly all, their collected dew for their special use, as if it were more beneficial to them when so applied than to their roots.

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* The French expression, that a river *bedews* (arrose) a country, is more correct than the English one, that it *waters* it. The watering of land is, properly, an artificial, the bedewing of it, a natural, process. The distance from its banks to which a river can saturate soil with water is rarely great; though it is in this acceptation that I have known many persons and authors to understand and use the phrase *watering*. A river, deep within its banks, will bedew a country as well as one bank-full; but the former acts as a drain to the land, and therefore does not directly moisten the surface of the soil. The term *watering*, in agriculture, should be limited to what we understand by *irrigation*.

Popular belief is often founded on correct observation, and sound practice is not unfrequently in advance of science. It also not uncommonly happens that the evidence of practical truths is received with scepticism, because we are unable, immediately, tó "interpret nature," and frame a satisfactory theory or explanation of the origin of particular phenomena. Hence the discovery of causes is of the highest importance to the arts, and a correct theory of any action so rapidly accelerates, extends, and perfects sound practice, that we cannot too highly prize its possession. This admitted truth, together with the rarity of Dr. Wells's 'Essay,' will, I trust, form a sufficient excuse for introducing the mention of phenomena explained by his theory of dew, which, though not directly affecting the soil itself, are of no slight consequence to the cultivators of the soil:—

> "The bare mention of this article," Dr. Wells observes, "will be apt to excite ridicule, it being an attempt to show in what way the exposure of animal substances to the moon's light promotes their putrefaction.
>
> "I have no certain knowledge that such an opinion prevails anywhere at present, except in the West Indies; but I conclude, from various circumstances, that it exists also in Africa, and that it was carried thence by negro slaves to America. It was entertained, however, by persons of considerable rank and intelligence among the ancients; for Pliny affirms it to be true, and Plutarch, after making it a subject of discussion in one of his Symposia, admits it to be well founded.
>
> "As moonbeams communicate no sensible heat to the bodies on which they fall, it seems impossible that they can, directly, promote putrefaction. But still a reason for ascribing such a power to them may be derived from their being received by animal substances at the very time that a real but generally unnoticed cause of putrefaction in warm climates (and it is in these alone the opinion I am treating of has ever prevailed) is taking place, which ceases to act as soon as the moon's light is excluded.
>
> "The nights on which a steady moonshine occurs must necessarily

be clear, and nights which are clear are almost always calm. A moonshiny night, therefore, is one on which dew forms plentifully; hence the expressions 'roscida' and 'rorifera luna,' employed by Virgil and Statius; and hence also an opinion, held, as appears from Plutarch, even by philosophers among the ancients, that the moon communicates moisture to the bodies which are exposed to its light.

"Animal substances are among those which acquire dew in the greatest quantity. To do this, indeed, they must previously become colder than the atmosphere; but, having acquired the moisture of dew, in addition to their own, they will, on the following day, be in that condition which is known by experience to favour putrefaction most powerfully in hot climates.

"The immediate cause assigned here for the putrefaction of animal substances which have been exposed to the moon's rays in a hot country, is the same as that given by Pliny and Plutarch; but they attributed the origin of this immediate cause, the additional moisture, to the peculiar humefying quality which they supposed that luminary to possess. This false theory has probably contributed to discredit, with the moderns, the circumstance which it was employed to explain."—*Essay on Dew.*

The belief that moonshiny or clear and dewy nights advance the process of putrefaction is not altogether confined to the ancients or to tropical climates, as was supposed by Dr. Wells. I had personally noticed the phenomenon of an increased putrefactive vigour in dung-heaps, after nights of a copious precipitation of dew, succeeded by hot days, some years before I was acquainted with Dr. Wells's 'Essay;' and I frequently conversed on this subject with an intelligent and observant farmer near Warwick, who corroborated my idea that such was the fact. Several farmers have recently confirmed this early opinion; and it is very common in France among the numerous peasant farmers near Paris. During a residence of several years in that country, my house being surrounded by small, unenclosed, and variously-cropped plots of ground, with a heap of night-soil or dung usually contiguous to each, the sense of smell somewhat too frequently informed me of the extreme activity in the putrefactive process. On inquiring of the peasants how it happened that, on certain mornings, the odour was so pungent, they commonly replied, "It is owing to the dew of last night, Sir;" but I do not recollect that any one of them imputed the effect to the moonbeams.

A knowledge of all that is requisite for the perfect preparation and management of dung is yet a desideratum in agriculture. Means of accelerating and retarding, at will, the putrefactive process, are much needed. The study of this art is certainly worthy of closer attention, and more exact experiment, than it has yet received. A moveable roof-shelter might be a useful adjunct to the sunken pit, or raised mass, in order to obtain command over the meteorological agents—air, heat, and water; each of which performs a part in the process; and more frequently to the injury than to the benefit of that species of manure which is home-made, and the most natural, if not the most beneficial, to the farmer.

> "I had often," says Dr. Wells, "in the pride of half-knowledge, smiled at the means frequently employed by gardeners to protect tender plants from cold, as it appeared to me impossible that a thin mat, or any such flimsy substance, could prevent them from attaining the temperature of the atmosphere, by which alone I thought them liable to be injured. But when I had learned that bodies on the surface of the earth become, during a still and serene night, colder than the atmosphere, by radiating their heat to the heavens, I perceived immediately a just reason for the practice, which I had before deemed useless."

He then ascertained by experiment that

> "A difference in temperature of some magnitude was always observed, on still and serene nights, between bodies sheltered from the sky by substances touching them, and similar bodies which were sheltered by a substance a little above them." "Possibly," he continues, "experience has long ago taught gardeners the superior advantage of defending tender vegetables from the cold of clear and calm nights, by means of substances not directly touching them, though I do not recollect ever having seen any contrivance for keeping mats, or such like bodies, at a distance from the plants which they were meant to protect."

It is a common practice in France to cover transplanted vegetables by linen sheets placed over sticks about two feet high. All the spare linen of my own house has been occasionally borrowed for this purpose; and I have laid my friends equally under contribution, until tender plants were sufficiently rooted and strong enough to bear complete exposure to the heat of the sun and the cold of the night.

May it not possibly be of advantage to the agriculturist to protect his potatoes, turnips, or other stored roots, from frost, by means of impermeable portable cloths stretched at a convenient height, instead of with earth, straw, &c., placed upon them? When substances touch each other, heat is conducted from the mass, and finally radiated away into space; cold results, and the roots are frost-bitten. The experiment may be worth a trial.

Mr. Graburn has communicated to me a remarkable phenomenon connected with hoar-frost, which is, perhaps, generally known to farmers, but, if not, the mention of it will convey a useful warning. He has remarked that the passage of a flock of sheep across a clover-field covered with hoar-frost, particularly young spring clover, is certainly followed by the destruction of every leaf over which the animals have passed. He further aptly observes, "You might trace the foot-steps of a thief across a clover-field covered with hoar-frost, at noon the day following, by the withering of the grass in his track." Knowing, as we do, that hoar-frost is a great protection to the leaf against further accession of cold, we might be disposed to attribute the death of the leaf, indirectly, to the shaking off of the frozen dew; but it is possible that the proximate cause is purely mechanical, and the withering the direct effect of injury from the tread, when the leaves are so crisp as to be in a state to be bruised by a sufficient weight pressing on them. The cause would be manifested by ascertaining whether the leaf, under the circumstances, would perish if the hoar were carefully brushed off it, and not trampled.

SECTION IV.

Experiments on the Temperature of Soils.

Schübler's Experiments.—This subject appears to have attracted the attention of several German philosophers, who have investigated it with their habitual minuteness of research. The excellent translation of Professor Schübler's learned work, in vol. i. of our Journal, renders it necessary to do little more than refer those persons to it who would pursue the same track of investigation. The inferences drawn by him, from experiments in the laboratory, confirm generally those of Davy and Leslie. They are, however, chiefly of an elementary nature, and, though more comprehensive and precise, perhaps even more accurate, than those of the British chemists, this valuable treatise seems to present nearly the same blanks, as respects useful practical experiments on the bed of the soil, as the labours of our own countrymen. We shall all agree in the truth of the Professor's concluding paragraph; viz. that

> "Those very soils may be fertile for one country which become no longer so for another, under a charge of external circumstances."

It is the difference in these external, *i. e.* in the meteorological conditions of the surface of our globe, which evidently renders identical systems of cropping, husbandry, and management inapplicable to all climes. It is this difference, also, which must clearly point out to the agriculturist that, if he would draw any useful deductions from experiments on the temperature of soil, they must be made on his own soil or on like soils similarly circumstanced. In Britain we have, generally speaking, to combat excess of moisture, accompanied by a low and inconstant solar heat. It is one of my objects to show that, *by establishing a free passage for water through the soil, the greater heat of the surface may be carried downwards, and the mean annual temperature of the mass of the soil thereby permanently raised.* This position, as well as the effect of removing excess of water, is well illustrated by Schübler in the section wherein he treats of the "*Influence of Moisture on the Warming of Soils.*" He states "*the depression of temperature arising from the evaporation of their water amounts to* 11¼° *or* 13½° *Fahr.*;" though the method by which he obtained this thermometric quantity is not mentioned, which is to be regretted. In the tenth section, however, wherein he treats of the "*Capacity of Soils to develop Heat within themselves on being moistened,*" the following passage occurs:—

> "The falling rain, in warm seasons, is many degrees colder than the lower stratum of the atmosphere, and the upper surface of the earth which it moistens; so that the earth in hot weather becomes rather cooled than otherwise."

This remark might seem to militate against the doctrine herein advanced, that the mass of the soil is warmed by rain when suffered to permeate it; but such opinion will, I think, vanish on further consideration, and by reference to Schübler's own experiments on the temperature of soils at Tübingen and Geneva.

At Tübingen his experiments were directed to the ascertainment of the mean highest temperature of the earth by a thermometer placed on its surface,—

> "the bulb being covered only $\frac{1}{12}$th of an inch high with earth. These observations were recorded in perfectly fine weather, between noon and one o'clock, whenever the weather happened to be perfectly fine at that part of the day."

It appeared that during the six hottest months, from April to September inclusive, the mean temperature of the surface was 131°·4. Now it is evident that, if rain fell upon the earth when it was so highly heated, the surface must be cooled by it; but it is equally evident that the substrata would be warmed; for the temperature of the atmosphere in the shade, which was also recorded at the same hour, was 70°· 4; and that of rain, had it then fallen, would have been much the same. Thus the rain, on reaching the earth, would acquire a temperature of about 100°, and communicate heat, as it descended, to the underlying portions of soil possessing a lower temperature.

His experiments at Geneva, in 1796, give the mean heat of the soil on its surface—at 3 inches—and at 4 feet below it. The observations were taken every day, in all weathers, and therefore, as described by the Professor, "in variable weather." The mean temperature denoted during the corresponding six months of the year before mentioned, was—

	Degrees.
On the surface	86·7
At 3 inches below	69·8
At 4 feet below	60
Temp. of air in the shade	59·7

On these results the author observes,—

> "The elevation of temperature by the rays of the sun was, therefore, considerably less" (than at Tübingen), "according to the average results of these observations, because the temperature of the upper surface of the earth on cloudy and rainy days often

accords exactly with that of the air; but, on the other hand, they give us more accurately the mean temperature of the ground, at some depth."

These experiments denote that, if the mean temperature of the rain, during the six months, accorded with that of the air, it would receive, on reaching the earth, an augmentation of thirteen and a half degrees of heat, and sink downwards at a temperature of 3°·4 higher than that of the soil at 3 inches deep, and of 13°·2 higher than that of the soil at 4 feet below the surface; thus supplying at the same time heat and moisture to the underlying soil. His table also shows that, on the mean of the whole year, the increase of temperature imparted to the soil by the rain would have been 2°·4 at 3 inches, and 6°·1 at 4 feet deep. Schübler's remark, therefore, "that the earth in hot weather becomes rather cooled than otherwise" by rain, is only applicable to the effect produced on its superficies, which is there beneficial.

The section of this author's Treatise on the "Influence of Moisture on the Warming of Soils" must be deemed incomplete, by reason of the absence of all reference to the warming effect of dew: which—whether it be considered as directly communicating heat to the surface of soil necessarily colder than itself at the time of its precipitation, or as diminishing to a great extent the radiation of heat from the earth to the heavens—is an agent which performs an energetic part in maintaining a sufficiency both of heat and moisture in the mass of the soil.

Leslie's Experiments.—In the Supplement to the 'Encyclopædia Britannica,' Art. Climate, written by Professor Leslie, will be found a table of experiments on the temperature of the earth, for each month of the years 1816 and 1817, at four different depths, viz. 1, 2, 4, and 8 feet below the surface. They were made at the instance of Mr. Ferguson of Raith. It is stated that the instruments were sunk "in a soft gravelly soil, which turns, at 4 feet below the surface, into quicksand, or a bed of sand and water." As it does not appear that these experiments were conducted with any other intent than to assist Leslie in some deductions relative to isothermal lines, and to the correspondence which might subsist between the mean annual atmospheric temperature of a given parallel of latitude, with that of springs and of the earth at certain depths, I have thought it unnecessary to extract the Table. Such deductions are, at best, very vague, nor are they calculated, in the slightest degree, to illustrate the physical properties of the various soils which form the crust of our globe, and which come within the province of the farmer: neither can they serve to assist his judgment in the management of them. The mere determination of the heat of the earth "at depths accessible to the cultivator" is useless, unless the observations be so conducted and recorded as to lead to the discovery of the circumstances which influence its temperature. I had the advantage of passing several days, about 20 years since, in company with Leslie, at the house of the late Lord Rosslyn in Fifeshire, and he took me to Mr. Ferguson's of Raith, to show me the thermometers in the ground. They were then, if I recollect right, two in number, and sunk in grass-land, the one descending 12 inches, the other 36 inches below the surface. Leslie's mind was, at this time, so pre-occupied with his newly-invented instruments, the photometer, differential thermometer, hygrometer, &c.—with which his hands and his pockets were filled—that I was unable to engage his attention, seriously, as to the practical use which I submitted to him might be made of observations on the temperature of soils. It was at this period I resolved to commence some experiments on the subject, but a fitting opportunity did not occur till 1837.

My own Experiments.—The site of the few experiments which I have now to describe as made by myself was a peat-bog called Red Moss,* near Bolton-le-Moors, in Lancashire, in its nature identical with Chat Moss, and approaching, in many parts of it, to that consistence which would cause it, in Scotland, to be designated a flow-moss, from its semifluid character. The depth of the bog, at the spot where the thermometers were inserted, was nearly 30 feet; and its temperature from 12 inches beneath the surface, downwards to the bottom, was uniformly 46°. I never found any variation to occur in the results afforded by thermometers placed at various depths during nearly three years' observations;

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* It was on this moss that the writer undertook the construction and conduct of Mr. Heathcoat's patent machinery for cultivating bogs by steam-power.

excepting in the winter of 1836, when the thermometer nearest the surface fell to 44° for a few days.

To this uniformity of temperature throughout the mass of the natural bog, I shall, subsequently, have to call your attention very particularly, as it seems to stamp with certainty the fact, that the more elevated temperatures, marked by the thermometers in the cultivated bog soil, were solely due to the change effected in its mechanical condition, and to the removal of stagnant water. There were no springs, so far as I could ascertain, in this bog, nor could I ever perceive that water rose from the bottom of any drain cut in it. The substratum, on which the bog had accumulated and reposed, consisted of a retentive white marl, abundantly mixed with limestone gravel. The temperature of the water drawn from the bottom of a coal-pit contiguous to the bog, and 300 feet deep, was 54°; and that from a bore, or Artesian well, near my house, and 160 feet deep, was invariably 52°.

The exposure of the bed in which the thermometers were sunk was perfect. There existed no bush higher than a tuft of heather within a radius of half a mile: not a ray, therefore, of the sun's light and heat could be intercepted (except by clouds) between his rising and setting.

The preparation of the bed was as follows:—The surface had been ploughed in 1836 by the steam-plough, to a depth of 9 inches, and was well pulverized. A plot of about 216 square yards area, clear of the drains, was divided into twelve beds intended for experimental culture. Each bed was 6 yards in length by 3 yards in breadth; and each was insulated from its neighbour, and from the surrounding bog, by an open drain, 24 inches broad at top, 12 inches at bottom, and 36 inches deep. Previously to opening these drains the plot had been surrounded by a catch-water drain 38 inches deep, communicating with a main drain 40 inches deep. The pulverized surface was then drawn to a heap, the enclosed plot dug 3 feet deep, the intermediate drains opened out, and the superficial soil replaced. In this state it remained through the winter of 1836 and 1837. Had the thermometers been ready, they would have been sunk in the bed as soon as prepared, but I could not obtain them from the maker, and plant them, till June 1st, 1837.

The thermometers were five in number, each being enclosed, throughout its length inserted in the ground, in an iron tube open at the bottom, with holes perforated round the bulb. They were firmly connected together by iron clamps, and the whole formed a stiff portable frame. The glass stems rose 10 inches above the ground. These were sustained against the wind or accident by a skeleton framing of metal carrying the scales divided into degrees and tenths. A hole being dug in the centre of one of the plots, the frame was let into it and set in the line of the meridian, so that the stems above-ground might cast the least possible shadow on it at noon. The soil was carefully replaced about the thermometers, so as to preserve, as nearly as might be, the order of its texture and consistence throughout the mass of the bed. At the same time a naked thermometer was inserted to the depth of 7 inches in the natural bog adjoining. I did not commence any regular register of the indications until June 7th, being desirous that the thermometers should first become well settled in the soil, and arrive at what may be called a true working state.

It is necessary to state that, on the bed in question, there was no kind of seed sown, nor a plant of any kind growing; my purpose having been to ascertain, in the first instance, the influence of the sun's rays, of rain, dew, and other atmospheric agents, upon the naked natural soil; and, subsequently, with other sets of thermometers, to acquire some knowledge of the effect which might be produced on the temperature of such soil by the admixture of manure and foreign substances. Whether this be the proper mode of proceeding, abler judges will decide; but it would appear to be difficult to detect the true physical characteristics of a soil by apparatus applied in the middle of a cornfield; and I thought it desirable to attempt to discover the properties of the natural soil first, and then of mixed soil, before proceeding to investigate similar phenomena on similar soils under crop. An industrious experimenter might carry on all these separate investigations at the same time; since, after his sets of thermometers are placed, he has only to observe and record. (See opposite page.)

1837.	Depth of the Thermometer bulbs below the Surface.					Time of Observation.	Direction of the Wind.	Temperature of the Air 4 feet from the Ground in the Shade.	Remarks.
June.	Inches. 31	Inches. 25	Inches. 19	Inches. 13	Inches. 7				
	Temp. °	Temp. °	Temp. °	Temp. °	Temp. °	Hour.		°	
7	46	47	48·4	50	52	9 A.M.	S.W. by S.	..	
	..	..	..	50·5	55	2 P.M.	W.	.	
8	..	..	..	50	51	9 A.M.	S.E.	..	Cold day.
	..	..	..	..	52·5	2 P.M.	..	..	
9	46·1	47·2	..	49	49	9 A.M.	E.	..	Cold and hazy.
	..	..	48·5	49·5	52·8	2 P.M.	W.S.W.	..	Clear and warm.
10	46·2	..	48·6	50	53	9 A.M.	S.	..	Rain during the previous night; splendid sun all day.
	..	..	..	50·5	54	2 P.M.	..	70	
11	46·3	47·4	..	51	55	9 A.M.	..	65	Throughout the day no visible cloud. Much hotter than the 10th; but, unfortunately, the air thermometer was broken after 10 A.M. The surface of standing water was 60° at that hour, and the surface of the bed 75°.
	..	..	..	52	56	10 ,,	..	68	
	..	..	..	..	57	11 ,,	..	..	
	..	..	..	..	57·5	Noon.	..	..	
	..	..	..	52·5	58	1 P.M.	..	..	
	..	..	..	..	59·1	2 ,,	..	..	
	..	47·5	48·7	..	59	3 ,,	..	..	
	..	..	..	52·3	57·5	4 ,,	..	..	
	46·4	..	48·8	52	57	5 ,,	..	..	
	..	..	..	51·5	56	6 ,,	..	..	
	..	..	..	..	55·5	7 ,,	..	..	
	..	..	..	51·3	55	8 ,,	..	..	
	..	..	..	51·2	55	9 ,,	..	..	
12	46·5	47·4	..	51	55	9 A.M.	W.S.W.	..	Warm showers.
13	46·8	48	48·8	52	59	2 P.M.	W.S.W.	..	Hot; a shower at 11 A.M.
14	47·2	48·4	50·4	53	60·4	Noon.	S.	..	Hot and dry.
15	47·25	48·6	50·8	53	57·6	9 A.M.	S.W.	..	Very hot; cloudless.
16	47·6	49	51·4	54·2	60	9 A.M.	S.W.	69	Sultry; cloudless.
	47·8	49·6	52	55	63	1 P.M.	..	72	Light high clouds.
	..	..	..	..	64	2 ,,	..	74	Dark cloud to windward.
	..	..	51·8	54	62·5	3 ,,	W.	78	Heavy thunder-storm, with lightning for ½ an hour.
	..	49·8	51·9	55	65	3¼ ,,	..	76	Temp. of rain 78°.
	..	..	52	57	66	3½ ,,	..	72	
	47·9	49·9	52·5	55·5	63	4 ,,	S.	68	Bright sun; visible vapour from pools and ditches
17	48	50	52·8	55·6	58	9 A.M.	S.	67	Brilliant morning.
	48·2	50·1	..	55·8	60·4	3 P.M.	..	74	Cloudless and hot.
18	48·25	50·2	..	55	56	10 A.M.	E. by S.	64	Hazy.

I have now to invite your attention to a few deductions from the tabulated results which we may be authorised to draw, notwithstanding the restriction of the observations to the short space of twelve days.

Firstly. The constant temperature of the *natural* bog, from 12 inches to 30 feet deep, was 46°; and the thermometer, planted in the same substance at 7 inches deep, constantly indicated 47° during the term of the experiments.

Now, the thermometer at 31 inches deep in the *worked* bed exhibited a maximum heat of 48¼°, having gradually gained 2¼°; and it was, apparently, still rising. The thermometer at 7 inches below the surface reached 66° after a thunderstorm, showing a maximum increase of 19°, and, on a mean of the thirty-five observations, of 10° over its fellow, at the same depth, in the natural bog.

We have here satisfactory evidence that the accession of heat was solely derived from meteorological agency, *i. e.* from action on the surface and not from the substratum, as the latter possessed, invariably, a lower temperature, which must have tended to diminish, rather than to increase, the heat finally acquired by the worked bed. And we may safely deduce from these facts, that the origin of the increased temperature is attributable to the change induced on the mechanical condition of the soil by drainage and pulverization, as no other changes were effected in it than those of comminution of its texture and the withdrawal of free water.

Secondly. The inference may be permitted, even from these few experiments, that, in the month of June, rainwater carries down heat, and raises the temperature of the subsoil; whilst the loss of heat by the strata nearer the surface is quickly restored by the sun's rays. By an inspection of the Table no doubt will be left on the mind as to the truth of these inferences. It appears that, at 7 inches deep, the temperature of the soil was subject to considerable diurnal increase and decrease, as well as from day to day, according to the state of the weather; that these variations became of less amount at lower depths; and that, at 31 inches, increase alone, for the time, was felt. Heat is conducted downwards so slowly by all bodies, and by moist substances particularly, that rain-water would appear, when allowed to permeate the bed, to be the most active agent in the propagation of heat to the subsoil. Accordingly, we find the lower thermometers to indicate accession of heat more quickly after rain than in dry weather; and had a rain of longer continuance fallen, instead of short showers, it is probable that the lower thermometers would have been affected much more rapidly, and have indicated higher temperatures, as no water was observed to have passed through the soil into the drain.

On the 11th of June I was able to devote an entire day to the observation of the thermometers. The results are interesting, by showing the steadiness of the increments and decrements of heat during a cloudless day, and by denoting the period of maximum temperature attained by the thermometer at 7 inches, which was about 2 P.M.

On the 16th I had foreseen the probability of a thunderstorm, and hastened to my thermometers to observe its effect. It is well worthy of remark, that after the temperature of the soil at 7 inches deep had attained its maximum, under the previous circumstances of the day, it was subsequently raised 3½° by the descent of the rain. It is also notable, that in half an hour after the cessation of the storm, the sun again shining brightly, and evaporation being visibly great from the surface, the earth at the same depth had lost 3° of its highest temperature, showing the rapidity with which heat is carried off by water in its transformation into vapour. It would have been highly interesting to have known, by other thermometers, the temperature of the surface when this storm fell, as the transition was almost instantaneous from bright sunshine to heavy rain; but I was unprovided with a sufficiency of these instruments.

An effect of importance—which might be predicated of all soils properly prepared to receive heat and water, and permit their descent—is traceable to the preparation of the bed: viz.—that the transmission of accessions of heat downwards continues during the afternoon of the day, and throughout the night, whilst the superstrata (but chiefly from 7 inches upwards) are losing some amount of their heat by conduction upwards, and radiation into space. The reverse may be expected to occur during the cold seasons of the year. when the heat accumulated and stored up in the subsoil will be drawn as from a reservoir. and supply part of the loss then taking place more freely near the surface.

As I have criticised the labours and experiments of others in this branch of science, it is right I should point out the deficiencies of my own, which are also numerous. The experiments related can, indeed, only be regarded as a slight contribution to our stock of knowledge on the subject —the investigation of which deserves to be commenced *de novo;* to be carried on simultaneously, if possible, by different observers, and with appliances of all the instrumental means which the existing state of science can furnish. The enumeration of the phenomena which demand attention—of the methods we possess, or still need, for ascertaining their force, or measuring their amount—will, perhaps, be the simplest and most useful form in which the criticism can be conveyed.

We require to know,—

1. The temperature of soils at depths accessible and profitable to the agriculturist.

The thermometer is all sufficient for indicating temperatures. It would be highly instructive and interesting to ascertain by thermometers sunk in the earth the temperature of a mass of drained and undrained soil at different depths down to the extreme depth of 6 feet. Self-registering thermometers would give the maxima and minima temperatures, but these instruments conduce to laziness in the observer; they give no information of the periods of the 24 hours when the maxima and minima occur, nor register the continually varying increments and decrements of heat at different depths, as they are affected by sunshine or cloud, by rain, wind, and other atmospheric changes, which should be diligently and faithfully recorded.

2. The temperature of the air, in the shade, near the earth.

3. The pressure of the air: for which the barometer suffices.

4. The temperature of the rain.

5. The quantity of rain; ascertained by the rain-gauge.

6. The quantity of water passed by drainage from a

measured extent of land, in order to compare it with the ascertained fall of rain on its surface.

There are many situations in which this object could be accomplished at a trifling expense, and the knowledge of such facts would open a new chapter of the book of nature to our view. All that has been written as to the quantity of water dismissed from the earth is too speculative and baseless to merit more than a passing notice; and no inquiry into these phenomena has, I believe, been instituted with the end of making them subservient to the practice or science of agriculture.

7. The dew-point; to be determined at frequent periods of the day and night.

The best-known hygrometer is Professor Daniell's, but, though simple and true, it has the disadvantage of requiring a manual experiment for every determination.

8. The quantity of dew deposited.

Of the amount of this item in the stock of Nature's fertilizing laboratory we are wholly ignorant; and though aware, as we must be, of the difficulty of ascertaining the fact required, there is no reason to despair of overcoming it if the attention of the many gifted men now attached to the science of meteorology could be brought to bear on the construction of a sufficient instrument.

9. The hygrometric condition of soil.

By this term is meant the amount of moisture which a soil may at any time contain. This quantity will depend, in a well-drained soil, on its bibulousness or hygrometric energy. If an instrument could be contrived to indicate, by simple insertion and inspection, the humid condition of the earth between the extremes of perfect dryness and of aqueous saturation, as the thermometer discloses heat of temperature, we should indeed become possessed of two ready and sufficient means of quickly ascertaining the principal phenomena on which the temperature of soils depends; we should be provided with tests, which would go far towards explaining certain causes and degrees of fertility, and possibly find ourselves armed with an expeditious method of deciding on the aids which a given soil might require for increasing its fructifying properties and power.

The mention of a desideratum is occasionally half way towards its fulfilment; and we may hope that the resources of science will avail for the supply of an instrument which would be so precious to the enlightened agriculturist.

Thus far had I written last year, as you are aware, and deemed my task terminated. Having had, however, the good fortune to obtain a record of observations illustrating, very forcibly, the necessity of draining retentive soils—by bringing within the scope of arithmetical computation the quantity of rain-water which is annually evaporated from the mass of the soil, "at depths accessible to the cultivator," and the quantity which either permeates porous or must stagnate in retentive soils—I have appended the following section to the foregoing discussion, as contributing to establish certain statistics of drainage, or, to use your own remark, "as striking a debtor and creditor account between the earth and the sky."

SECTION V.

On the Quantity of Rain compared with the Quantity of Water evaporated from or filtered through Soil; with some Observations on the Quantity of Rain-water discharged by Drains.

WE are indebted to Mr. John Dickinson, of Abbot's Hill, near King's Langley, Herts (the eminent paper-manufacturer), for a register, extending over the period of the last eight years, of the quantity of rain which has fallen in his locality, and of the quantity which may be presumed to have passed through the soil. The first datum is determined by the common rain-gauge; the second is derived from a gauge invented many years since, for this special purpose, by the illustrious Dr. Dalton. And hereby we obtain, very unexpectedly, as regards both the facts and the extensive range of observations, experimental illustrations of the desiderata numbered 5 and 6 (page 34). The construction of the rain-gauge needs no remark, and the Dalton gauge is equally simple. It consists of an open-top cylinder or rain-receiver sunk vertically in the earth level with its surface, having a false bottom perforated with holes, like a cullender, which supports three feet depth of soil within the cylinder, through which, and through the cullender, the excess of the rain—or the portion not evaporated—filtrates to the close bottom of the vessel; and this communicates, by means of a small pipe, with a vertical tube, whose diameter bears some definite proportion to that of the receiver, and is sunk so much lower in the earth as to have its top nearly on a level with the bottom of the receiver. Thus, all the water which permeates the soil contained within the rain-receiver flows into the tube, and is measured by a float carrying a divided stem, and indicating, in parts of $\frac{1}{100}$th of an inch, the quantity of rain which has entered it. The measuring tube has a cock at the bottom for evacuating its contents from time to time, and bringing the scale to zero.

Mr. Dickinson's rain-receiver has a diameter of 12 inches, and is 36 inches deep to the false bottom ; it was originally filled with the soil of the country, a sandy gravelly loam, and has constantly had grass growing on it. The contents of the receiver, therefore, represent fairly the natural state of such soil; whilst the gauge indicates the quantity of water which a drain, at the depth of 3 feet, would have to convey away. The proportion which this quantity bears to the rain is obtained by comparison with the rain-gauge; and their difference gives the quantity evaporated, assisted by the action of the succulent grasses. We may, however, for the present purpose, consider the whole of this last quantity under the term evaporation.

It will be interesting and useful to agriculturists to learn Mr. Dickinson's object, as a manufacturer, in ascertaining and registering phenomena of this nature. Having several mills on the river Colne or its tributaries, it was a matter of importance to him to be able to calculate the power of water on which he might depend for use at different periods of the year; and having noticed that a considerable period elapsed after rain, owing to the extent and stratification of the country, before the springs were affected by it, he fixed a rain and Dalton gauge to assist his judgment in forming an estimate of the amount and duration of their flow according to the varying seasons, and the proportionable water-power on which he might count. These registers, combined with observation, have since enabled him to regulate his manufacturing operations, and to foresee what dependence he could place on the mill-streams, and to what extent he should require the aid of steam-power for fulfilling his contracts and engagements. This is a very remarkable and honourable instance of the application of meteorological " science to practice."

Nor is this all—for the knowledge acquired by means of these instruments, and the exposition of the results of rain and filtration proved by them, together with a just acquaintance with the area and nature of the soils of the district supplying the streams (about 120 square miles), enabled Mr. Dickinson, two years since, to demonstrate the impracticability of a scheme for furnishing the Metropolis with water proposed to be drawn from the valley of the Colne, which must have inflicted irreparable injury on the mill-owners, at the same time that it would have proved, in all probability, an abortive speculation to the adventurers. Such are the various and often unexpected fruits of exact knowledge. It was Mr. Dickinson's communication of his experiments to the Institution of Civil Engineers last year which introduced me to his acquaintance, and has enabled me to apply his acquired facts to the subject of agricultural drainage.

The annexed Table, No. I., contains the monthly and annual indications of the two gauges for the years 1836 to 1843 inclusive; those of the rain-gauge being, Mr. Dickinson informs me, generally corroborated by another gauge kept by the Grand Junction Canal Company about 8 miles distant. Table II. gives the mean result of the eight years' observations for each month, and the whole period, in terms of the depth of rain which fell on the surface — of the amount which filtered through the Dalton gauge—and of that which was evaporated or again restored to the atmosphere in the shape of vapour—with two columns showing the proportion per cent. of filtration and evaporation. Table III. presents to view the total amount of rain which fell during each year, with the per-centage of filtration and evaporation. And Table IV. illustrates the quantity of rain and the proportion of water disposed of by filtration and evaporation during the six hotter and six colder months of each year respectively. To these last Tables I have added columns exhibiting the weight of rain in tons per acre, as that expression may convey to the farmer a clearer idea of its amount than the more usual mode of stating it in inches of depth. By means of this tabular analysis we shall find the phenomena, as they may be applicable to agriculture, clearly brought before us.

The first important fact disclosed is, that, of the whole annual rain, about 42½ per cent., or 11$\frac{3}{10}$ inches out of 26$\frac{6}{10}$ inches, have filtered through the soil; and that the annual evaporative force is only equal to the removal of about 57½ per cent. of the total rain which falls on any given extent of earth 3 feet in depth (Table II.).

By a closer scrutiny we learn (Table IV.) that only about 25½ per cent. of the rain which falls from October to March inclusive, passes back to the atmosphere by evaporation in the same period; whereas from April to September inclusive, about 93 per cent. is evaporated. It appears then that there is even a balance on the side of rain over evaporation during the six hottest months; and we discover only two years, 1840 and 1841, in which no filtration occurred within that period. Table II. shows that in August the soil is in its driest state; but, even in that month, some filtration took place in 3 out of the 8 seasons recorded. It will be understood, that, though a near balance is shown to subsist between rain and evaporation during the six hottest months, on an average of years, the hygrometric condition of a soil, *i. e.* its state of wetness or dryness at any particular time, is not indicated by the Dalton gauge. A soil may be in a state of drought, or of humid saturation, at different times during these months, and according to the season. It is, however, manifest, from these registers, that if all the water derived from rain during the six colder months were allowed to accumulate in a soil, such land must be perpetually *wet;* and coupling this fact with the performance of drains, which I am now enabled to exhibit, it appears that six months are expended in maintaining, by the sole unaided force of evaporation, an undrained retentive soil in a tolerably uniform

	TABLE I.																TABLE II.				
Months.	1836.		1837.		1838.		1839.		1840.		1841.		1842.		1843.		Mean of each Month, and of eight Years.				
	Gauges.		Gauges.		Gauges.		Gauges.		Gauges.		Gauges.		Gauges.		Gauges.		Rain.	Filtra-tion.	Evapo-ration.	Filtra-tion.	Evapo-ration.
	Rain.	Dalton.	Rain.	Dalton.	Rain.	Dalton.	Rain.	Dalton.	Rain.	Dalton.	Rain.	Dalton.	Rain.	Dalton.	Rain.	Dalton.					
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	Per Cent.	Per Cent.
January .	2·40	2·32	2·40	2·10	0·31	0·04	1·40	1·04	3·95	3·05	1·50	..	1·36	0·60	1·46	1·25	1·847	1·307	0·540	70·7	29·3
February .	2·04	2·04	2·85	2·92	2·65	0·86	1·45	1·51	1·32	1·00	1·02	..	2·02	2·10	2·42	1·95	1·971	1·547	0·424	78·4	21·6
March . .	3·65	2·51	0·75	0·01	1·55	2 73	1·92	1·22	0·34	..	1·65	0·53	2·20	1·62	0·88	..	1·617	1·077	0·540	66·6	33·4
April . .	2·57	1·74	1·32	..	1·35	..	1·65	0·71	0·34	..	1·85	..	0·47	..	2·10	..	1·456	0·306	1·150	21·0	79·0
May . .	0·70	0·03	0·94	..	0·84	..	1·22	0·10	2·62	..	1·68	..	1·85	..	5·00	0·74	1·856	0·108	1·748	5·8	94·2
June . .	1·80	0·01	1·86	..	2·85	..	3·31	0·05	1·33	..	3·00	..	2·00	..	1·56	0·25	2·213	0·039	2·174	1·7	98·3
July . .	2·29	0 10	1·30	..	2·35	0·09	4·36	0·15	1·18	..	2·80	..	1·93	..	2·09	..	2·287	0·042	2·245	1·8	98·2
August .	2·24	0·15	3·00	0·05	0·95	..	3·65	0·09	1·90	..	3·62	..	1·40	..	2·66	..	2·427	0·036	2·391	1·4	98·6
September	2·60	0·07	1·38	0·05	2,47	0·03	3·22	1·50	2·31	..	4·00	..	4·50	1·30	0·63	..	2·639	0·369	2·270	13·9	86·1
October .	4·55	3·82	1·55	0·02	2·68	0·07	1·68	0·09	1·50	..	4·40	5·99	1·41	0·30	4·82	0·91	2·823	1·400	1·423	49·5	50·5
November	3·95	3·14	2·05	0·18	3·55	2·91	4·40	4.70	4·25	2·57	4·28	4·87	5·77	5·00	2·45	2·70	3·837	3·258	0·579	84·9	15·1
December	2·21	1·72	1·70	1·62	1·58	1·84	3·02	3·75	0·40	1·57	2·30	2·80	1·52	0·84	0·40	0·30	1·641	1·805	−0·164	100·0	00·0
Total .	31·00	17·65	21·10	6·95	23·13	8·57	31·28	14·91	21·44	8·19	32·10	14·19	26·43	11·76	26·47	8·10	26·614	11·294	15·320	42·4	57·6

TABLE III.

Total of each Year.				
Years.	Rain.	Filtration.	Evaporation.	Rain, per Acre.
	In.	Per Cent.	Per Cent.	Tons.
1836	31·0	56·9	43·1	3139
1837	21·10	32·9	67·1	2137
1838	23·13	37·0	63·0	2342
1839	31·28	47·6	52·4	3168
1840	21·44	38·2	61·8	2171
1841	32·10	44·2	55·8	3251
1842	26·43	44·4	55·6	2676
1843	26·47	36·0	64·0	2680
Mean	26·61	42·4	57·6	2695

TABLE IV.

April to September inclusive.							
Years.	Rain.	Filtration.	Evaporation.	Filtration.	Evaporation.	Rain, per Acre, Filtrated.	Rain, per Acre, Evaporated.
	In.	In.	In.	Per Cent.	Per Cent.	Tons.	Tons.
1836	12·20	2·10	10·10	17·3	82·7	212	1023
1837	9·80	0·10	9·70	1·0	99·0	10	982
1838	10·81	0·12	10·69	1·2	98·8	12	1082
1839	17·41	2·60	14·81	15·0	85·0	263	1500
1840	9·68	0·00	9·68	0·0	100·0	. .	980
1841	15·26	0·00	15·26	0·0	100·0	. .	1545
1842	12·15	1·30	10·85	10·7	89·3	131	1099
1843	14·04	0·99	13·05	7·1	92·9	100	1322
Mean	12·67	0·90	11·77	7·1	92·9	91	1192
October to March inclusive.							
1836	18·80	15·55	3·25	82·7	17·3	1574	330
1837	11·30	6·85	4·45	60·6	39·4	693	452
1838	12·32	8·45	3·85	68·8	31·2	855	393
1839	13·87	12·31	1·56	88·2	11·8	1246	159
1840	11·76	8·19	3·57	69·6	30·4	829	362
1841	16·84	14·19	2·65	84·2	15·8	1437	269
1842	14·28	10·46	3·82	73·2	26·8	1059	387
1843	12·43	7·11	5·32	57·2	42·8	720	538
Mean	13·95	10·39	3·56	74·5	25·5	1052	360

NOTE.—The quantities of rain in the columns headed Filtration represent the required performance of drains in retentive soils. One-tenth of an inch of rain in depth amounts to 10·128 tons per acre.

moist condition, whilst deep covered drains relieve the same soils of excess of humidity in a very few hours after every fall of rain, even in the wettest season. Table IV. shows that the mean excess of rain-water to be disposed of during the six coldest months by some other process than evaporation, amounts to no less a weight than about 1050 tons per acre.

Evaporation is the only *natural* agent for diminishing the quantity of water absorbed by retentive soils, but it is not at our command. When such soils are perfectly saturated, the superfluity must either stagnate on the surface or flow away from it: and proof is here offered that the force of evaporation is scarcely equivalent to the duty required of it during one half of the year; also that it greatly falls short of the requisite power during the six colder months. The invention of subterranean drains supplies an effective artificial method of compensating the deficiency of the evaporative force in our climate, and it is capable of placing the retentive soil in the same favourable condition, as respects meteorological agency and the fruition of every agricultural process, as soils naturally porous, and free from stagnant water. But, it must constantly be borne in mind, that, in order to assimilate this artificial process to that of nature, drains should be deeply laid, as the floor of the drains forms the limit of their action, and determines the depth below the surface at which water must still remain in a state of nearly constant excess and stagnancy.

A study of the results registered in these Tables puts us in possession of many other facts of import to the agriculturist, as enforcing the warning—which experience cannot but have taught him—to adopt every appliance at his command for placing his soil in such condition as to derive the greatest benefit and the least evil from elemental influences; for, so variable are the seasons, that no average can properly display the changing amounts of meteorological quantities and forces. It seems from Table I. that the discharge of water by drains occurs, on the average, during seven months of the year. In 1840 and 1841, however, rain was in excess over evaporation only during four months; though in the first year $21\frac{4}{10}$ inches of rain fell, whilst in the second the earth received $32\frac{1}{10}$ inches, or 50 per cent. more rain in the latter than in the former year; yet the soil was equally dry in both years on the mean of the six hottest months, for the evaporative force was able to relieve the soil of all the rain that fell, though the quantities were so widely different, being $15\frac{8}{10}$ inches in 1841, and only $9\frac{6}{10}$ inches in 1840. But, turning to the six colder months of the same years, we find the case reversed, for the proportionate evaporation in 1840 was double that in 1841. It appears, too, that in 1836, when the quantity of rain was only about one inch less than the maximum in 1841, the force of evaporation was 13 per cent. less, and water filtered through the gauge in various proportions, during every month of that year, and the same in 1839. Thus, in preparing soil to receive the utmost benefit and the least evil from rain, however slight or excessive, it should be put into a state to refuse holding water in excess, but be capable of absorbing humidity freely and retaining it deeply; whilst the drains should admit water with facility, and convey it away with despatch.

Observations on the Quantity of Rain-water discharged by Drains.

The quantities of rain and filtration denoted by Mr. Dickinson's gauges are daily registered, and this record has enabled me to ascertain a remarkable coincidence between the action of the Dalton gauge and that of Mr. Hammond's inch-pipe drains, as reported by me to the Royal Agricultural Society, in Journal, vol. iv. p. 375. It appears, according to the rain-gauge, that $\frac{48}{100}$ths of an inch of rain fell on the 7th and 8th of November last; and by the Dalton gauge, that on the 9th $\frac{46}{100}$ths, or nearly the whole of this quantity, had passed through it. It was on the 9th that I inspected the drainage of Mr. Hammond's farm, recording the fact that, after a rain of about 12-hours' duration on the 7th, I found the drains on the 9th, in a nine-acre piece, 3 feet deep, just dribbling, and those in a hop-ground adjoining, 4 feet deep, exhausted; Mr. Hammond having observed, previously to my arrival, that the greatest stream at the outfall of each drain amounted to about the half-bore of the inch pipes. The times occupied in the discharge of the water by the gauge and the drains may, therefore, be considered to be identical, and as comprising about 48 hours from the commencement of the rain. In drawing this parallel between the action of the gauge and these drains, I am presuming that the fall of rain at Penshurst was equal to that at King's Langley; and I think this may be assumed to be near enough to the truth, as I have learnt that a nearly similar downfall ($\frac{5}{10}$ths of an inch) was recorded at Birmingham northwards, and a rain of similar duration occurred at Brighton southwards.

This experimental corroboration of the sufficiency of such small drains will have its weight with practical men; but I am further able to demonstrate, by simple arithmetical computation, how very small is the quantity of water required to enter the crevice formed by the imperfect junction of two pipes. The rain-gauge informs us, that $\frac{48}{100}$ths of an inch in depth of rain fell upon each square foot of surface in the observed time of 12 hours. This quantity is equivalent to 69$\frac{1}{10}$ cubic inches, or 2½ pounds, which, divided by 12 hours, gives little more than $\frac{2}{10}$ths of a pound per square foot of surface per hour for the weight of the rain.

The drains were 24 feet asunder, and each pipe a foot in length, so that each lineal foot had to receive the water falling on 24 square feet of surface, equal to 60 pounds, or 6 gallons; and as the time which this quantity occupied in descending through the soil and disappearing was about 48 hours, it results that 1¼ lb., or one pint, per hour, entered the drain through the crevice existing between each pair of pipes. Every one knows, without having recourse to strict experiment, how very small a hole will let a pint of water pass through it in an hour, being only one-third of an ounce per minute, or about twice the contents of a lady's thimble.

The weight of rain, per acre, which fell during the 12 hours amounted to 108,900 lbs., or 48$\frac{6}{10}$ tons, which, on the whole piece of nine acres, is equal to 437$\frac{4}{10}$ tons; and each drain discharged 19 tons, equal to about $\frac{4}{10}$ths of a ton per hour, on the mean of 48 hours; but when the flow was at the greatest, I find that each drain must have discharged at the rate of five times this quantity per hour, which affords proof of the faculty of the pipes to receive and carry off a fall of rain equal to 2½ inches in 12 hours, instead of half an inch, a fall which is quite unknown in this climate. Half an inch of rain in 12 hours is a very heavy rain. I learn from Mr. Dickinson, that his rain-gauge has never indicated so great a fall as 1¼ inch in 24 hours; and from Dr. Ick, the curator of the Birmingham Philosophical Institution, that only on five occasions has the rain there exceeded 1 inch in 24 hours, during the same period of 8 years; the greatest quantity having been $1\frac{6}{10}$ inch on Dec. 4, 1841. We may, therefore, consider the fact of the sufficiency of inch-bore pipes for agricultural drainage to be fully demonstrated both by experience and experiment.

I will now mention an experiment which every farmer is competent to make, and which cannot fail to throw light on the action and effect of his drains, and on the relative condition of different pieces of land as to porosity, or filtrating activity—I allude to the simple ascertainment, by measure, of the quantity of water discharged from different drains, after rain, in the same time. In reply to numerous inquiries on this subject, I have only succeeded in obtaining sufficiently exact information from Mr. Hammond, whose intelligence had led him to make the experiment without any suggestion from me. He states—" I found after the late rains (Feb. 17, 1844), that a drain, 4 feet deep, ran 8 pints of water in the same time that another 3 feet deep ran 5 pints, although placed at equal distances." The circumstances under which this experiment was made, as well as its indications, deserve particular notice. The site was the hop-ground before referred to, which had been under-drained 35 years since to a depth varying from 24 to 30 inches; and though the drains were laid somewhat irregularly and imperfectly, they had been maintained in good action. Mr. Hammond, however, suspecting injury to be still done to the plants and the soil by *bottom* water, which he knew to stagnate below the old drains, again under-drained the piece in 1842 with inch pipes, in part to 3 feet, and in part to 4 feet in depth, the effect proving very beneficial. The old drains were left undisturbed, but thenceforth ceased running, the whole of the water passing below them to the new drains, as was to be expected. The distance between the new drains is 26 feet, their length 150 yards, the fall identical, the soil clay. The experiment was made on two drains adjoining each other, *i. e.* on the last of the series of the 3 feet, and the first of the series of the 4 feet drains. The sum of the flow from these two drains, at the time of the trial, was 975 lbs. per hour, or at the rate of 19½ tons per acre in 24 hours—the proportionate discharge, therefore, was 12 tons by the 4 feet, and 7½ tons by the 3 feet drain. No springs affected the results. Hence, we have two phenomena very satisfactorily disclosed; 1st, that the deepest drain received the most water; 2nd, that it discharged the greatest quantity of water in a given time—the superficial area of supply being the same to both drains. It would appear, then, either that the deeper drain had the power of drawing water from a horizontal distance greater by the ratio of 8 to 5 than the shallower drain; or that the perpendicular descent of the water was more rapid into the 4 feet drain; or that its increased discharge was owing to both these causes combined. The phenomenon of a deep drain drawing water out of soil from a greater distance than a shallower one, is consistent with the laws of hydraulics, and is corroborated by numberless observations on the action of wells, &c.; but the cause of the deeper drain receiving more water *in a given time* is not so obvious. An opposite result, as to time, would rather be expected from the fact of water falling on the surface having to permeate a greater mass of earth, both perpendicularly and horizontally, in order to reach the deep drain. A natural agricultural bed of porous soil resembles an artificial filter, and it is unquestionable that the greater the depth of matter composing such filter, the slower is the passage of water through it. In stiff loams and clays, however, but more particularly as regards the latter earth, the resemblance ceases, as these soils can permit free ingress and egress to rain-water, only after the establishment of that thorough net-work of cracks or fissures which is occasioned in them by the shrinkage of the mass from the joint action of drains and superficial evaporation. These fissures seem to stand in the stead of porosity in such soils, and serve to conduct water to drains rapidly after it has trickled through the worked bed; it is possible, too, that in deeply drained clays of certain texture the fissures may be wider, or more numerous, in consequence of the contraction of a greater bulk of earth, than when such soil is drained to a less depth. However this may be, it is asserted by several respectable and intelligent farmers in Kent, who have laid drains very deeply in clays and stiff soils, that the flow from the deepest drains invariably commences and ceases sooner than from shallower drains, after rain. On this interesting and unexplored subject I hope to be able to furnish you with multiplied observations after next winter, and trust also to receive the co-operation of members of the Society in making them in different soils, and with due regard to all those phenomena which may influence the results, or be detected by them.

The consideration of the depth of drains has been too generally limited to the mere exigencies of culture and implements, combined with the natural desire to restrict expense when the materials used were dear, and the cost of earth-work great. These adventitious circumstances have certainly tended to obscure from view the true principles on which drainage should be founded, and on which the utmost benefits to be derived from it depend. The question of distance between drains is important on the score of expense, and it will be wise to err on the right side, and keep within safe limits; but insufficiency of depth can only be remedied by a new outlay. So far as experience can illuminate the subject, we know that many agriculturists have, a second time, drained their fields to a greater depth; it may, however, be doubted whether any one has taken up deep drains, and placed them nearer the surface, or nearer together. The system of deep drainage has, doubtless, been encouraged by the cheapness, lightness, and approved action of the pipe-tiles, combined with the more moderate cost of the earth-work incident to their small dimensions, and to the facility of laying them. The aggregate cheapness of the work has set the mind of the farmer free to contemplate more exclusively and attentively the perfection of the end in view; and it is well worthy of remark, that experiment and experience have rapidly induced the adoption of a system of parallel drains considerably deeper, and less frequent, than those commonly advocated by professed drainers, or in general use. I gave several instances of this practice in Kent in the report of last year, already alluded to, and it is rapidly extending. Mr. Hammond stated to you (*Journal*, vol. iv. p. 47), that he drained "stiff clays, 2 feet deep, and 24 feet between the drains, at 3*l.* 4*s.* 3*d.* per acre," and "porous soils, 3 feet deep, 33½ feet asunder, at 2*l.* 5*s.* 2*d.* per acre." I now find him continuing his drainage at 4 feet deep, wherever he can obtain the outfall, from a conviction, founded on the experience of a cautious progressive practice as to depth and distance, that depth consists with economy of outlay as well as with superior effect. He has found 4 feet drains to be efficient, at 50 feet asunder, in soils of varied texture—not uniform clays—and executes them at a cost of about 2*l.* 5*s.* per acre, being 18*s.* 4*d.* for 871 pipes, and 1*l.* 6*s.* 6*d.* for 53 rods of digging. Communications have been recently made to me, by several respectable Kentish farmers, of the satisfactory performance of drains deeply laid in the Weald clays, at distances ranging from 30 to 40 feet, but I have not had the opportunity of personally inspecting these drainages.*

The following little table shows the actual and respective cost of the above three cases of under-draining, calculated on the effects really produced, *i. e.* on the masses of earth effectively relieved of their surplus water at an equal expense. I conceive this to be the true expression of the work done, as a mere statement of the cost of drainage per acre of surface conveys but an imperfect, indeed a very erroneous idea of the substantive and useful expenditure on any particular system. This will be apparent on reference to the two last columns of the table, which give the cost in cubic yards and square yards of soil drained for one penny at the above-mentioned prices, depths, and distances:—

Depth of the Drains in Feet.	Distance between the Drains in Feet.	Mass of Soil drained per Acre, in Cubic Yards.	Mass of Soil drained for 1*d.*, in Cubic Yards.	Surface of Soil drained for 1*d.*, in Square Yards.
2	24	3226⅔	4·1	6·27
3	33½	4840	8·93	8·93
4	50	6453	12·00	8·96

I may here observe, that Mr. Hammond, when draining tenacious clays, chooses the month of February for the work, when he lays his pipes (just covering them with clay to prevent crumbs from getting in), and leaves the trenches open through March, if it be drying weather, by which means he finds the cracking of the soil much accelerated, and the complete action of the drains advanced a full season. The process of cracking may, doubtless, be hastened both by a choice of the period of the year in which drains are made, and by such a management of the surface as to expose it to the full force of atmospheric evaporation.

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* The cost above given can only be taken as that of the particular case; see page 63.

Recurring to the foregoing Tables, it must be noticed that the mean annual fall of rain, as therein registered, is below the average of Britain, whilst the force of evaporation is probably higher than the average; and the monthly as well as annual amounts of filtration and evaporation may be expected, in different latitudes, localities, and soils, to vary greatly from these records. Similar observations obtained on different soils, and in various parts of the country, when combined with the indications of thermometers sunk in the earth, would put us in possession of that condition of soil which may not be improperly termed its *climate,* of which no certain knowledge can be deduced from purely meteorological phenomena, but upon which the atmospheric climate of a district is known greatly to depend.

Meteorologists have recorded, for many years, the amount of terrestrial evaporation, as denoted by a gauge invented by Mr. Luke Howard, and have considered it as "indicative of the quantity of moisture taken up by the atmosphere from the earth;" but this instrument only denotes the evaporation from a dish of water placed on the earth's surface, and therefore supplies no fact of direct use to the agriculturist, for cultivated soils are not under these circumstances, and the power of the sun's rays in heating soil is but indifferently represented by their effect in transforming water into vapour. The difference between the indications of the Howard and Dalton gauges is most remarkable. Professor Daniell states (*British Almanac*) the mean annual rain in London to be 22·199 inches, and the mean evaporation 23·981 inches, or 1·782 inches more than the rain; and the results recorded at the Birmingham Philosophical Institution for 1843 are—

rain 26·716 inches, evaporation 31·982 inches, or 5·266 inches more than the rain. But we learn from the Dalton gauge that, in Hertfordshire, out of 26·614 inches of rain only 15·32 inches were restored to the atmosphere—the remainder passed through the earth into the rivers; and this is the real fact on comparing the amount of rain with the amount evaporated from soil 3 feet deep.

We must never forget that accurate and multiplied quantitative facts form the only substantial basis of science; and observations of the rain and Dalton gauges would be usefully varied by placing the latter at different depths, as at 1, 2, 3, and 4 feet, or more, below the surface, and filled with a diversity of soils, whence information may be expected to arise of great practical value to the agriculturist.

JOSIAH PARKES.

11, *Great College Street, Westminster.*

ESSAY II.

LECTURE

ON

DRAINING.

By JOSIAH PARKES, Esq.,

CONSULTING ENGINEER TO THE ROYAL AGRICULTURAL SOCIETY OF ENGLAND.

READ BEFORE THE SOCIETY AT NEWCASTLE-UPON-TYNE.

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LECTURE ON DRAINING.

My Lord Portman and Gentlemen,

In fulfilment of the wish of the Council of the Society, and in anticipation that I, in common with its members, shall benefit by the remarks and larger knowledge of others, I have undertaken to appear before the present assemblage of agriculturists with the view of illustrating some of the principles and rules of practice in the art of land-draining. By so doing I do not think that I, or others who may follow me, shall be open to the charge of presumption, inasmuch as we may doubt if there lives the man, having acquaintance with the climate, soil, and agriculture of Britain, who would have the hardihood to dispute the assertion that drainage is beneficial, or the fact that vast districts in our island still require to be relieved from an injurious amount of water stagnant in its soil and stagnating too near its surface. I apprehend, therefore, that I may commence this paper by assuming—by taking for granted—unphilosophical and inadmissible as such a procedure would be in a doubtful case—that land-drainage is an art and a practice of acknowledged value and necessity; and that we are met here not to dispute about the propriety of draining wet lands, but simply to discuss the means of rendering the art of drainage efficient and economical, and to impart to each other our respective knowledge as to the modes of arriving at those desirable ends. I further apprehend that it should be our course to state, with precision, such practice as we may have severally pursued, its effects, and the causes to which good or ill-success in a particular practice may, in our opinion, be ascribed. I imagine that we shall, in this way, best fulfil the object of the Council in inviting this discussion, for I subscribe heartily to the doctrine enforced in the Report of our Council to the general meeting in May last, viz. that "a clear knowledge of cause and effect, under given circumstances, and a detail of the particular cases to which such knowledge is applicable, is, in their opinion, the only safe science to be recommended to their members." There is nothing contained in this declaration of the Council to discourage experiment, as has been feared and suggested to me by some of its members—from which circumstance partly I refer to it—since "safe science," if the term has a meaning, is simply expressive of that determinate state of knowledge which is founded on facts; and we cannot obtain facts but through experiment, observation, and experience. Let me mention a definition of science as propounded by that illustrious traveller and philosopher, Alexander von Humboldt, in his recently published work, 'Cosmos,'* p. 71. He observes, "Science begins at the point where mind dominates matter, where the attempt is made to subject the mass of experience to the scrutiny of reason; science is mind brought into connexion with nature." There is no difference in the sense of the two definitions, and the recommendation of the Council will put the members at their ease who have information to add to the common stock, and will, I trust, absolve them and myself from all charge of egotism, or desire of display, in speaking of our individual performances or opinions.

Experience has proved that a soil surcharged with water cannot perfect crops—that excess of water is an impediment to the due mechanical division of the active soil—that it diminishes the fertilizing power of every species of manure—that it lowers the temperature of the mass of the bed—that it precludes the free entrance and change of atmospheric air—that it prevents the free descent of rain through the soil, and its timely evacuation. The existence of water in excess is far from being confined to those absorbent and tenacious descriptions of soil which have obtained the name of clays. My own observation of the soils of Britain leads me to the perception and belief, that fully as large an area of its extent, consisting of loams, and of earths still more siliceous, need draining quite as much as the stiff and compact clays. Water is permanently maintained too near the surface of many soils, whose natural texture for a few feet deep would allow to it a free passage downwards, were it not for the existence of a clay or of some other impassable medium, at depths more or less great, which uphold water. The evils referable to the excess of water in soils are rendered peculiarly apparent by comparing such water-logged land with those free, deep, naturally dry and warm soils, as they are called, which are so coveted by farmers; of which every one wants a slice, but which are so rarely to be met with, in comparison with the over-wet or too dry portions of the superficies of our island. The art of draining land is to assimilate the naturally wet to the naturally moist soil, in so far as that can be accomplished by so simple an operation, and its effect upon the texture and physical condition of wet land will be the greater or less according to the knowledge and skill employed in performing the operation. In a former paper on this subject, entitled 'On the Influence of Water on the Temperature of Soils' (Journal, vol. v. p. 119, Essay 1 in this publication), I endeavoured to bring together and lay before the Society a succinct history of the properties of water in its several states as a fluid, a solid, and a vapour or steam, and to show its effects upon soil; together with the action of other natural forces inherent in soil, or dependent on meteorological phenomena. I need not again refer in detail to the points discussed in that essay, nor further than to express the conviction, that without a pretty clear knowledge of the nature of those bodies, forces, and phenomena—without, in fact, informing ourselves of the properties of the tools with which Nature works, our own efforts and performances must be imperfect, and come short of the mark.

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* 'Cosmos; a General Survey of the Physical Phenomena of the Universe.' Bailliere, 219, Regent Street, London.

A number of instances of draining, observed at different periods, and published by others as well as myself, has induced in me a firm belief in a very early-formed opinion, that the general drainage carrying on in this country is of a depth too shallow to realise the valuable results which a given expenditure of money is capable of effecting. Growing experience, with extended observation, have only served to strengthen my confidence in the superior efficiency of a deeper system of drainage, and the fortuitous discovery of the simple cylindrical pipe-conduit came in aid of those agriculturists and drainers whose convictions and practice were enlisted in the same cause. The Society owes to Mr. Pusey the first announcement that there were drain-tiles of that form in use, in his paper 'On the Evidence on the Antiquity, &c., of Thorough-Draining,' published in the May Journal of 1843; and in the same year, at the Derby show, Mr. John Read exhibited a few specimens of pipes. This was followed by an investigation into the use and merits of pipes made at the instance of the Council by myself in Kent, and reported in the second part of the Journal of the same year. There existed only at that time a machine of a rude kind for manufacturing drain-pipes, but through the wide-spread information conveyed by the pages of their Journals, and the prizes offered by the Society for superior machines, we have arrived, in the short space of three years, at that agreeable dilemma which actually renders the selection in our show-yard of the most meritorious pipe-machine a matter of no little difficulty. From a machine having the faculty of producing about 1000 feet of pipes per diem, we have advanced, in less than three years, to the faculty of making fully 10,000 feet in the same time; in truth, the power of production by many of these machines is considerably, though usefully, greater than the requirements of any tilery. It may be also asserted that we have, during the same period, vastly enlarged our knowledge of the art of draining. We have come to consider, scientifically, what is meant by draining. Instances of the truest kind for guiding our judgment have been elicited from the practice of many farmers living in different counties, and occupying different kinds of soil; we have had collected and placed before us in juxtaposition the fact and the effects of drains made at different depths, not only in similar soil, but in the same field; we have the fact before us, well ascertained by various careful observers and practitioners, that lands which have been drained to a certain depth without effecting a cure of wetness have entirely lost their dropsical habit when under-drained to a greater depth. The evidence to my mind is irresistible that a less depth of drain than 4 feet in any soil will not be accompanied by those beneficial results which we obtain at that, and in some soils by a still greater depth; and if time permitted, I should not doubt the bringing before you a mass of evidence, drawn from my own practical experience, as unimpeachable as it would be convincing, that drains executed to these depths are not only the most efficient, but the most economical, when the conduit is formed of cylindrical pipes.

Before, however, entering on the detail of one or two interesting and peculiar examples of the effect of deep drains, I am desirous of making known to the Society the opinions of an excellent author, the third edition of whose work was printed in the year 1652, and in which the recommendation and theory of deep drainage, as applied by him to water-meadows and swamps, are so clearly and powerfully laid down, that it would be difficult to give them in better language. It is right, too, to assign the merit of discovering, or of the earliest assertion of sound practical principles to whomsoever we may consider to be entitled to the praise. The author of this work was a Captain Walter Bligh, signing himself "A Lover of Ingenuity:" it is quaintly entitled 'The English Improver Improved; or the Survey of Husbandry Surveyed:' with several prefaces, but specially addressed to "The Right Honourable the Lord General Cromwell, and the Right Honourable the Lord President, and the rest of the Honourable Society of the Council of State." In his instructions for forming the flooding and draining trenches of water-meadows, the author says of the latter,—"And for thy drayning trench, it must be made so deep that it goe to the bottom of the cold spewing moyst water, that feeds the flagg and the rush; for the widenesse of it, use thine own liberty, but be sure to make it so wide as thou mayest goe to the bottom of it, which must be so low as any moysture lyeth, which moysture usually lyeth under the over and second swarth of the earth, in some gravel or sand, or else, where some greater stones are mixed with clay, under which thou must goe half one spade's graft deep at least. Yea, suppose this corruption that feeds and nourisheth the rush or flagg should lie a yard or four foot deepe, to the bottom of it thou must goe, if ever thou wilt drayn it to purpose, or make the utmost advantage of either floating or drayning, without which thy water cannot have its kindly operation; for though the water fatten naturally, yet still this coldnesse and moysture lies gnawing within, and, not being taken clean away, it eates out what the water fattens; and so the goodnesse of the water is, as it were, riddled, screened, and strained out into the land, leaving the richnesse and the leanesse sliding away from it." In another place he replies to the objectors of floating, that it will breed the rush, the flagg, and mareblab, "only make thy drayning-trenches deep enough and not too far off thy floating course, and I'le warrant it they drayn away that under moisture, fylth, and venom as aforesaid, that maintains them, and then believe me, or deny Scripture, which I hope thou darest not, as Bildad said unto Job, 'Can the rush grow without mire, can the flagg grow without water?' Job viii. 11. That interrotion plainly shewes that the rush cannot grow, the water being taken from the root; for it is not the moystnesse upon the surface of the land, for then every shower should increase the rush, but it is that which lieth at the root, which, drayned away at the bottom, leaves it naked and barren of relief."

The author frequently returns to this charge, explaining over and over again the necessity of removing what we call bottom-water, and which he well designates as filth and venom, observing, "I am forced to use repetitions of some things, because of the suitableness of the things to which they are applied; as also because of the slowness of people's apprehension of them, as appears by the non-practice of them,—the which, wherever you are so drayning and trenching, you shall rarely find few or none of them wrought to the bottom." As to the distance between the draining and floating trenches, he prescribes no certain rule, saying, "If the land is sounder and drier, or lieth more descending, thou mayest let it (the water) run the broader; and as thy land is moyst, sad, rushey, and levell, let it run the less breadth or compasse;" thus exhibiting a far more correct and intimate acquaintance with his subject than is often to be found among the water-meadow artificers of the present day; my opinion being that many of these meadows have been converted into swamps for want of a systematic and deep under-drainage. Our author gives a most just account of the cause of those isolated boggy places and swamps so often formed on the slopes of hills, and at their foot, and describes the mode of treating them, so as to effect a perfect cure, which coincides with the best practice of the present day; but I fear to be tedious, and therefore refrain from this quotation.

For all drainage purposes he reprehends shallow trenches, observing, in respect to bog-drainage, "But for these common and many trenches, oft times crooked too, that men usually make in their boggy grounds, some one foot, some two, never having respect to the cause or matter that maketh the bog; I say, away with them as a great piece of folly, lost labour, and spoyle, which I desire as well to preserve the reader from, as to put him upon a more profitable experiment; as to destroying the bog, it doeth just nothing, only taking away a little water which falls from the heavens, and weakens the bog nothing at all, and to the end it pretends is of no use." Finally, he describes, admitting such a work to be more expensive, but more efficacious and durable, the use of deep covered drains, placing at the bottoms of the trenches "good green faggots, willow, alder, elm, or thorne," or in firmer stuff, "pebble-stones or flint-stones, and so fill up the bottom of thy trench about fifteen inches high, and take thy turf and plant it as aforesaid, the green soard downwards, being cut very fit for the trench, so as it may joyne close as it is layd down; and then, having covered it all over with earth, and made it even as the other ground, waite and expect a wonderful effect through the blessing of God." He prescribes also, in all cases excepting for water-meadows, the driving the drains right up and down the fall of the land. In this account of draining water-meadows and swampy lands one cannot but recognise very sound principles, and these are represented by Captain Bligh as having been put into practice by himself, copied by others, and as having raised the value and rent of land so treated from a few shillings to two, three, and four pounds per acre. There is no indication in this work of any systematic plan of under-draining generally wet and retentive soils; but the author seems, nevertheless, to have been thoroughly penetrated with its importance, referring to the "incredible expense" it would occasion, and he prescribes in this difficulty the ridging up wet clay lands, or the laying them in balks. As no instance, or "precedent," as Captain Bligh terms it, of any general under-draining is referred to by him, we may, I think, conclude that this practice has had its origin within the last two hundred years, struggling onwards to perfection through the difficulties presented by the absence or expensiveness of good materials wherewith to form permanent subterranean water-conduits.

In the course of my operations as a drainer I have met with, or heard of, so many instances of swamp drainage executed precisely according to the plans of this author, and sometimes in a superior manner—the conduits being formed of walling stone, yet at a period long antecedent to the memory of the living—that I am disposed to consider the practice of deep drainage to have originated with Captain Bligh, and to have been preserved by imitators in various parts of the country; since a book which passed through three editions in the time of the Commonwealth must necessarily have had an extensive circulation, and enjoyed a high renown. Several complimentary autograph verses, written by some imitators and admirers of the ingenious Bligh, are bound up with the volume, which I beg to put into your Lordship's hands as proof of the statements I am making. I find also, not unfrequently, very ancient deep drains in arable fields, and some of them still in good condition; and in a case or two I have met with several ancient drains six feet deep, placed parallel with each other, but at so great a distance asunder as not to have commanded a perfect drainage of the intermediate space.

The author from whom I have so largely quoted is the earliest known to me who has had the sagacity to distinguish between the transient effect of rain and the constant action of stagnant bottom-water in maintaining land in a wet condition. It is this subterranean water, as it may not be improperly termed, to which excessive and injurious wetness is attributable; and if such water be not removed and kept down at a depth exceeding the power of capillary attraction to elevate it too near the surface, no drainage can be efficient. It is chiefly through capillarity that those soils are maintained in a sufficiently moist state for vegetative perfection, on digging into which we do not discover any free water within several feet of the surface. The effect of rain is to thoroughly moisten such soil, gravity carrying down below the excess, or that portion which the soil cannot absorb or retain. Evaporation takes place from the surface of the land, and, as each atom of moisture is taken up into the atmosphere, its place is supplied by another atom communicated by the contact of the particles of soil, the more superficial acting on the deeper particles like so many pumps to elevate the water and supply the loss. In this way the deep rich loams, to which I have before adverted as so rare and so coveted, are maintained in a nearly constant condition of moisture suitable to the necessities of plants. It may and does, though rarely, happen, that even such soils during long-continued droughts suffer, that is, become too dry; but the attentive observer will notice a very beautiful and powerful provision of nature to prevent excessive dryness. During the night evaporation from the surface of soil commonly ceases, to commence again when the rays of the sun impinge upon it; but capillary action is constant and of equal intensity both by night and by day, so that we have, on the average, twelve hours per diem of the sun's influence to produce evaporation, and twenty-four hours of capillary action to supply the loss from below, and maintain a tolerably uniform hygrometric or moist condition of the active soil. It is, I believe, consistent with the universal opinion, that drained lands do not burn nor suffer from drought so soon or so much as those soils which are wet at all periods of the year, except during the hottest months. This phenomenon is explained by the fact of a retentive soil swollen by water contracting so much by the loss of its water, that it is almost inaccessible to air from which to obtain moisture. After drainage the mechanical texture of such soils becomes gradually changed; pulverization takes place in the subsoil in a manner precisely similar to the change we see produced in fresh turned-up soil well exposed to the atmosphere; such change of texture in the mass below is doubtless slower than in the superficial soil, but it is equally certain to occur.

Perhaps no more striking illustration of the great importance of securing free ingress to air and free egress to water in the mass of the soil can be given than that which is derived from the fact that, by allowing land to rest without cropping it—in short, by fallowing it—fertility is renewed, and this effect is produced solely by supplies furnished from the inexhaustible magazine of the atmosphere. The atmosphere is our cheapest, it is a boundless storehouse of manure: then why not let it freely and deeply into our soil? The earnestness with which I appeal to the landed proprietary of Britain to drain more deeply, and abandon the ofttimes abortive and at all times incomplete system of shallow drains, is derived from the indications of experience; and to those well informed of the superior economy and efficiency of the deeper system, it is painful to behold the sums of money daily buried in the soil with such good intentions, but with comparatively so little useful effect. In respect, however, of the depth at which drains may, with a certainty of action, be placed in a soil, I pretend to assign no rule; for there cannot, in my opinion, be a more crude or mistaken idea than that one rule of depth is applicable with equal efficiency to soils of all kinds: the same remark applies in regard to assigning any common rule of distance between drains, which may be greater or less according to the depth of the drains, and the texture of the particular soil. It must be self-evident that water will flow through a gravel, or a sand or a loam, with less obstruction to its passage than through a clay, and easier through one clay than through another containing different proportions of silica and alumina. There are also many other properties of soil to which the drainer has to pay attention in determining depth and distance, such as tightness or compactness, uniformity, or intermixture of soils of a different texture in the line of his drains in the same field, &c. &c. All these circumstances will affect both his practice and the cost of the work. It consists with my own practice at the present time, that drains are being executed at depths of from 4 to 6 feet, according to soil and outfall, and at distances varying from 24 to 66 feet; complete efficiency being the end studied, and the proof of such efficiency being that, after a due period given for bringing about drainage action in soils unused to it, the water should not stand higher, or much higher, in a hole dug in the middle between a pair of drains than the level of those drains.

The cost of drainage is in like manner affected by the texture of soils, their stoniness, &c.; and rates of work are being paid, varying from 3*d.* to even 1*s.* 6*d.* per rod (5½ yards), causing the cost of drainage per acre to vary from 2*l.* to even 5*l.* per acre, according to circumstances.

The following is an instance of the utility, the necessity I ought to say, of well examining soil—of ascertaining, in fact, what we have to deal with—before commencing drainage. I was invited in February last to visit the property of the Duke of Wellington at Stratfield-Saye. I found a particular grass-field, which it was desirable to drain, very wet, and it was thought that no drainage deeper than about 2 feet would have any effect upon it, as drains in other parts which had been made 3 feet 6 inches deep had not effected much more good than the shallower ones. It was also thought that the mass of clay beneath would be found almost impervious to water, as cracks had only opened in hot seasons to about 15 inches deep. However, we had the turf and mould borne off a space of about 5 feet square and 22 inches deep, when a bed of yellow plastic clay appeared. Into this bed, which was soft and easily worked by the hand, a hole was sunk. But a very slight quantity of water oozed into the hole until we reached about 4 feet 3 inches, when the hole rapidly filled with water. It was still clay, but evidently of a more porous nature, and there a mass of free water resided. It was immediately apparent that the cause of the upper clay and surface soil being so wet, in defiance of the shallow drains, was now discovered; for as the upper clay reposed on what, relatively, may be called a pillow of water below, the capillary force, always in action, continually sucked up this water, and supplied the incumbent soil with a perpetual excess of fluid. The shallow drains might have done their duty in removing the water of rain—the surface-water—but they could in nowise affect the liberation of the bottom-water. An experimental drain was then made, 5 feet in depth and 350 yards long, laid with 1½-inch bore-pipes. Clay was puddled in over this line of pipes up to 2 feet 6 inches from the surface, and another line of similar pipes was then laid; so that we had a shallow and deep drain in the same trench, the object being to measure the relative discharges of water from each, and the lower drain was puddled over to prevent as much as possible the top water from mixing with the bottom. The result was that the bottom drain discharged, from the commencement, a stream averaging one gallon per minute during seventy-six days, being equal to nearly 5 tons every twenty-four hours. The run then rapidly diminished, and speedily came to drop only. A second 5-feet-deep drain had been made 36 feet distant, so as to insulate a space of land on one side of the experimental drain, and it will be found that, taking the length of 350 yards with a breadth of 12 yards as affording water to the bottom drain (6 yards on each side of it), no less than an area of 4200 square yards of water, 5½ inches deep, had been removed by this one drain. At first the upper line of pipes answered to rain, but this action soon ceased, and the whole of the water finally passed off through the lower and deep drain. The land is now reported to me as giving way in cracks to a greater depth than formerly, so that an efficient drainage may be certainly expected. The following is an analysis of the clays in question, taken at 22 inches and 4 feet 6 inches deep respectively beneath the surface, by Mr. Phillips:—

	Clay at 22 inches, per cent.	Clay at 4 feet 6 inches, per cent.
Silica	59·0	72·9
Alumina	23·5	13·4
Peroxide of iron	8·1	6·6
Carbonate of lime	1·0	0·8
Water, with a little carbonaceous matter, slight traces of magnesia, and sulphate of lime, and loss	8·4	5·5
Carbonate of magnesia	0·0	9·8
	100·0	100·0

This is only one out of numerous examples which I could cite of the lower clay of a field being more porous than that nearer the surface. Beds of gravel, sand, or mixed earth also often prevail under superficial clay at depths not too great to enable the drains to be placed at distances considerably wider apart than if the drains were laid in the clay, effecting thereby the removal of the subterranean water, permitting the descent of rain-water, and causing a less outlay of money.

The capillary force, or *succulency*, of soils varies greatly, and is often very noticeable. It has occurred to me, in digging test-holes previous to drainage, to find the water standing in them not nearer the surface than 3 feet, yet the surface soil has been so wet that water would drop from it on squeezing with the hands. This exhibition would determine me to bleed such soils to the depth of 5 feet at least, and such drainage has been accompanied with complete success.

Although I am not a practical farmer, I think that I may very confidently recommend to farmers the laying land absolutely flat after efficient drainage. It is the practice of many good agriculturists in the stiffest clays, who consider that even a crease left on the surface is injurious to drainage. In addition to several recorded opinions on that head, I will quote a letter recently received from Mr. Andrew Thompson, the intelligent bailiff of the Right Honourable Charles Arbuthnot, who has drained part of his farm—a very strong clay—4 feet deep, and whose account of the effects is to be found in the last Journals.

Woodford, July 4, 1846.

Dear Sir,—On the arable land, which we have drained to the depth of 4 feet, I have not found it necessary to maintain any open water-furrows. I am not at all an advocate for water-cuts or surface-drains of any description on arable land, it being my belief that, when they are used for the purpose of carrying off the water after heavy rains, they are also the means of washing away a quantity of fine soil, which might otherwise be retained on the land. I believe that if even the most retentive of soils were drained to a considerable depth, and rendered friable by the aid of Read's pulveriser, there would not then be any use of open water-furrows on that description of land. In reply to your other question I have to say, that adjoining one of the fields, which was drained to the depth of 4 feet, is a field of the same subsoil (a strong blue clay), which was only three years ago drained in the old-fashioned way of "shallow draining." I have frequently observed that after heavy rains the water began to run first from the deep drains, and that, when the shallow drains did run, they did not appear to me to discharge the same quantity of water to the same quantity of land as the deep drains.

I was quite against draining land so very deep until I saw the great advantages derived from it.

Yours, &c.
ANDREW THOMPSON.

The last remark made by Mr. Thompson, as to the deep drains giving issue to rain-water, in land under precisely similar circumstances, before shallow drains, agrees with the observation of a great number of farmers whose land has been so drained; and it would be difficult to cite a more apposite proof, I think, of the superior condition into which the mass of the soil is brought by deep drainage. That this should occur in a field where shallow drains exist in the neighbourhood of deeper drains, and within their influence, would be naturally expected, as the water keeps on descending below the level of the higher and until it reaches the level of the lower vents, where it meets with free water, and then begins to travel horizontally to the drain. The reason, however, why the deeper drain in one field should begin to discharge before another and a shallower drain in another field, or in a very distant part of the same field, having precisely similar soil, is not quite so obvious. I have this day received from a tenant farmer in Yorkshire an account of an observation of his, that a 4-feet drain began to run five minutes earlier after rain than another drain 16 inches deep at a distance, but in the same field. Some experiments are being made which may elucidate this action, which tells so favourably for the deeper drainage.*

There are some causes of stoppage to subterranean drains, though fortunately few and limited in their extent, with which every drainer should be acquainted, and prepared to encounter and vanquish as he best may. The first and most extensive evil of this kind to which I will refer is the deposit of a substance of an unctuous sticky nature, in drains laid in soils containing much ferruginous matter. On this point I was particularly questioned by his Grace the Duke of Richmond, Chairman of a Select Committee of the House of Lords, appointed last year "to inquire into the expediency of a legislative enactment being introduced to enable possessors of entailed estates to charge such estates with a sum, to be limited, for the purpose of draining and otherwise permanently improving the same." I was asked, "Do not stone drains invariably clog if there is water in them impregnated with iron?" My reply was, "I have no doubt that the ferruginous matter, such as I have often seen accompany the water of drainage, would stop up stone drains;" and, in conversation, his Grace informed me, that he had estates in Scotland infested to such a degree with ferruginous matter, that the deposit of iron in drains seemed an almost invincible obstacle to the drainage of these lands. Since that time, and in various parts of England, my attention has been practically and specially required to discover the cause, and, if possible, a cure for this disease. It may not be thought tedious that I narrate what I know on this subject, as there are thousands of acres of land subject to this evil, the drainage of which depends on discovering some means of rendering it permanent.

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* See the Report of the Evidence given before the Select Committee of the House of Lords in 1845, for information on this head. Mr. Robert Neilson's statement of the result of intermingling deep and shallow drains in the same field is highly instructive and to the purpose.

When applied to by Sir Robert Peel last autumn to drain some portions of his estates at Drayton Manor—and he knew that my system consisted in the use of small pipes in preference to other conduits—he earnestly called my attention to this cause of stoppage, which had been a continued source of vexation, expense, and defeat, in draining the park and other parts of the property. Sir Robert accompanied me throughout the grounds to be first drained, and showed me the evidences of this red deposit at the mouths of drains, and the spewing masses of it on ditch-banks, &c., leaving me to deal with the enemy according to my judgment. It will be conceived that I felt the full force of the difficulty, and there was but little experience, so far as I knew, of the use of small pipes in soils similarly infested. Yet I had confidence in pipes, as preferable to all other conduits, from the compression of the run of water into the smallest required volume, and therefore as more likely to prevent deposits from occurring or accumulating in them than in larger conduits. I was acquainted with one case, and only one, in which very small pipes, an inch bore, had been used, and have continued to act well for several years, without obstruction, in a boggy soil charged with iron, though the ditches into which the pipes, always running full bore, discharged their water, require clearing once or twice a-year to keep them open. I also felt additional confidence in the sufficiency of small pipes, as I proposed laying them with collars, which would further help to cover and diminish the size of the crevice between each pair of pipes, and close it against the entrance of solid matter. However, I devoted an entire week to the examination of old drains, many of which were quite stopped up with earth and iron deposit mixed; of these some were composed of the common horse-shoe tiles laid without soles, and others with soles. The drains through which water was continually running were chiefly open, exhibiting great quantities of the deposit at their mouths, and one drain, formed of 6-inch pipes, conveying much water, exhibited the iron copiously as a precipitate when the line was broken and a pipe removed, which exposed the water to the atmosphere; cesspools communicating with the atmosphere at top, and into which some drains entered, were also lined with deposit. I examined several drains serving as mains, and particularly at their point of junction with minor drains, and I found one of these drains about 6 feet in depth, and very well constructed, to be nearly closed with what appeared to be a pure specimen of the deposit, having the red colour of peroxide of iron, and of a pasty consistence. This particular mass of deposit had occurred at the junction of a branch with the main, about 30 or 40 yards from the higher end or origin of each drain, and where the run of water would necessarily be less than as it approached the outfall; and I have found at Drayton Manor, and many other places where ferruginous matter abounds, that stoppage from its deposit is much more frequent towards the higher than nearer the outfall end of a line of drain; and for the very obvious reason, that the flow of water there is less both in amount and velocity, and consequently of less force than as it approaches the end of its course. This specimen was analysed by Mr. Richard Phillips, of the Geological Museum, Craig's Court, London. Mr. Phillips at once told me it was peroxide of iron, but I wished it to be analysed that I might know whether, and to what extent, the iron was pure or incorporated with other matter. The following is Mr. Phillips's report of its nature and of the manner of its production:—

"*Museum of Geology*, 13*th Dec.* 1845.

"I have submitted the deposit occurring in the drain to analysis, and I find it to consist of, after drying—

Silica and alumina, with a trace of lime .	49·2
Peroxide of iron	27·8
Organic matter	23·0
	100·0

"The large amount of peroxide of iron shown in the above analysis appears to me to be in consequence of the iron existing originally in a lower state of oxidation, in which state it has been dissolved by carbonic acid, and formed by the decay of organic matter in the soil, and then carried away by the drainage water; when by subsequent exposure to atmospheric air it has been converted into insoluble peroxide. The other ingredients in the deposit would appear to have been carried down mechanically, in consequence of their existing in a very minute state of division."

It thus appeared from the analysis that only 27·8 per cent. of the deposit consisted of iron, and that the remainder, nearly three-fourths of the whole, consisted of foreign matter. This analysis powerfully fortified my hopes that the drains I was making might remain permanently open, if their mechanical structure were such as to admit water only, and no other earthy matters than such as might be chemically dissolved in the water, in which case it was apparent that I should reduce the enemy to be contended with by nearly three-fourths of his strength, and direct against him, for expulsion, a more concentrated stream of water, by reason of the smaller dimensions of the conduit. Between November last and the present time some miles of drains have been executed in the soils referred to, abounding with bog-iron ore, locally called "pox-stone," the same as I have met with in North Devon under the name of "black-ram," and in Somerset under the title of "iron-mould." In other parts it is called by its proper name. It occurs in masses, both large and small, sometimes in beds. It is intensely hard, and interferes much with both the economy and despatch of digging the drains. It is the protoxide of iron of the chemists, and furnishes, by its fine dissemination in the soil, the matter dissolved by means of carbonic acid in the water which enters the drains, becoming peroxide in the manner described by Mr. Phillips. The term iron, or rust of iron, would convey to the mind an idea that this ferruginous matter was heavy, and would quickly settle; but when it is considered that all substances chemically dissolved in water, and precipitated, are infinitely fine, each atom is, in a practical sense, light, and easy of removal; and, in reality, this substance is seen to issue from the mouths of drains in the form of light, flocculent, floating little masses, which settle when the water is quiet, or are easily brought to rest by stones, grasses, &c.; and this has actually given rise to a notion with some people, that it was a vegetable substance, and grew in drains.

Up to the present time scarcely a trace of this ferruginous matter is to be discovered at the outfall of any one of the pipe-drains laid at Drayton Manor; there is scarcely even a stain of its presence visible on the ends of any of those pipes which discharge into open ditches, and where it might be expected to exhibit itself; so that the result is very encouraging. The time, however, has been too short to permit us to indulge in absolute certainty as to their permanent action; yet I may mention one or two circumstances as confirmatory of the fact that earthy matter does not enter the pipes, and that therefore nothing has to be dealt with but the iron. There is no appearance of any sand or other earthy bodies having accompanied the water of drainage, which is brilliantly clear; and in one field where I had the opportunity of continuing a line of pipes through the field into a head of water which I could stop out or allow to flow through the drain 290 yards long at will, no earth was washed out by it, thus giving proof that none had entered the drain with the water of drainage.

The subsoil generally in Drayton Manor Park consists of gravel intermixed with fine and very heavy sand, alternating with, or broken in places by, a marly clay very retentive of water. It contained much water, test-holes made in the winter before drainage standing nearly full of water. It was chiefly by the pickaxe that the trenches had to be opened, spades being of little use in the gravels. The sides of the drains fell in and closed so much that it was difficult, and in some parts impossible, to keep an entire line of drain open before the pipes were obliged to be laid, so that the worst parts had to be done by instalments, the pipes being laid and covered up as the work proceeded—for, if not so done, the spewing sand was forced up from the bottom and through the sides by the pressure of water. All was secure, however, when the collared pipes were laid and covered in. One drain, about 105 yards long was laid in a quicksand, by using inch pipes completely sheathed in another larger pipe, and no packing or cover was employed. This drain, which is about 6 feet deep, has never exhibited, at its outfall, a grain of sand; the water is beautifully pellucid, and has maintained a discharge, varying however with rain or drought, of about two gallons per minute. I consider this method of sheathing pipes to form a drain of the most permanent kind through any species of quicksand or soft soil; packing may be a useful and even necessary adjunct in certain very fluid and fine media, but, when a drain thus formed is carefully laid and filled in, my belief is that it will resist the entrance of all matter except water. To use the apt expression of one of my workmen, "nothing else can get in when the water *sighs* into the drain so quietly."

Another cause of obstruction to drains is the entrance into them of the roots of trees and plants. Of the former several cases have been reported to me as having occurred, and probably no species of close under drain yet constructed can be considered to be absolutely safe from the roots, if laid within the range of their travels; and the great distance from the parent tree to which roots will travel in search of food is well known to every agriculturist. It would be venturing too much to say that a root will not enter drains by any, even the smallest conceivable, crevice or pore which will admit water; for cases have been mentioned to me almost justifying the belief that roots have insinuated themselves through Roman cement. They seem, however, to be very capricious and choice in their attacks, for I have seen drains which have continued perfectly free in their action for years, adjoining fences and plantations, whilst a drain at a greater distance has been choked by roots. In the two or three cases observed by myself, I have found that a single thread-like root alone has entered, and then worked its way up against the run of the water, increasing into a hairy mass, something like the brush of a fox, and growing in length sometimes to several yards, until it closes the drain as completely as if it were stopped full of clay. In situations where drains must be laid near to trees, I would advise the keeping as far off as circumstances permit, and the providing each row of pipes, if joining a main, with a cesspool at their junction, in order that the discharge may be visible and examined occasionally, which would soon detect a stoppage if it occurred. But it will be wise, in all cases, if people will have hedge-row trees, that the drainer so plan his operations as to keep as wide of them and fences as possible—but better still to get trees felled wherever they occasion a feeling of doubt as to their affecting the permanency of the drainage, or cause it, in respect of the direction or depth of the drains, to be other than complete. If trees, as in parks, are in the way of drains, I advise the sheathing of the pipes on approaching within 20 yards, and I frequently diverge from the line and pass round the tree to regain the true line of drainage.

With stoppages from the roots of plants I have only very recently become acquainted, but this evil does occur, though fortunately it is of very rare occurrence. The first case known to me took place this year in a field on an estate of Mr. W. Wolryche Whitmore, at Lebotwood, in Shropshire.

A tenant of his laid a pipe-drain last March in a boggy piece of ground, very wet and spongy, which was sown with turnips. The drains were found in many places to be completely stopped with very fine roots in October. It seems to be difficult, indeed impossible, to pronounce from what plant these roots proceeded. I sent specimens of them to Professors Lindley and Daubeny, who kindly examined them, but neither of these botanists is able to decide on the parent plant, to which the roots unfortunately were not traced when the pipes were taken up. The drains were shallow, not exceeding 2 feet 6 inches deep anywhere. The boggy soil contained many sorts of weeds, as crowfoot, coltsfoot, rushes, and docks, of which there was abundant evidence when I was on the spot some weeks afterwards. The pipes sent me contained much earth, which had got into them with the roots, and I understand that several of the pipes were almost stopped with soil alone; but it is also true that others, in which the roots had worked, were free of earth. From all the evidence I could collect on the spot, I am disposed to consider this stoppage by roots to have originated in bad laying of the pipes by the farmer, and insufficient depth in a very foul piece of land. It is however a case of warning, and one to excite vigilance of observation. I have now a drain laid deeply in the same soil with pipes collar-jointed, and other drains to test any difference in future action and phenomena.

It is important that every case of the stoppage of drains from the entrance of roots should be well investigated; but we may rest quite satisfied, from our long experience of under-drainage, that instances of this evil will only be of casual, and, probably, of merely local occurrence. With the exception of the one case cited, I have not met with a single case of stoppage from the roots of plants in pipes; but it is evident that if the roots of weeds or cultivated plants were in the habit of preferring to burrow in a drain rather than in the bed of soil, a pipe-drain would be as liable to be choked as any other form of drain.

I will now refer to one or two natural aids to drainage.

Besides the porosity of soils, by which they receive and part with water more or less readily, according to their openness or retentiveness, there are other adjuncts or means auxiliary to its reception and discharge. It has not occurred to me to excavate many clay soils for drains in which there are not perceptible what experienced and observant drainers aptly call water-veins. The clay is divided, as it were, into plates, masses opening or parting from each other like the leaves of a book, between which, thin as the vein is, an evident passage of water has taken place. These partings may have been originally occasioned by vertical cracks from the surface, which have never entirely closed again, and so served to conduct away some of the rain-water to more porous and absorbent strata. It is a matter of fact that in all clays in which these water-veins occur in the greatest number I have found drainage to be effected the most speedily, and I practically use the perception of their presence as some guide to the distance at which I determine to place the drains from each other.

But the most active and potent of the drainer's auxiliaries is the common mining earth or dew worm. The earliest written notice which I have seen of the utility of the earthworm in drainage is to be found in Mr. Beart's article on draining (Journal, vol. iv. p. 212), in every word of whose remarks I concur. Earth-worms love moist but not wet soils; they will bore down to, but not into, water; they multiply rapidly in land after drainage, and prefer a deeply-drained soil.

On examining with Mr. Thomas Hammond, of Penshurst, Kent, part of a field which he had deeply drained after long previous shallow drainage, we found that the worms had greatly increased in number, and that their bores descended quite to the level of the pipes. Many worm-bores are large enough to receive the little finger, and it is possible that one worm has several bores for his family, and refuge-holes from rain. I have very recently found worms twisted up into knots, and berthed in a nidus formed by the side of the vertical bore, and in communication with it by a lateral hole about an inch long, forming in appearance a comfortable retreat.

My valued and much lamented friend, Mr. Henry Handley, informed me of a piece of land near the sea in

Lincolnshire, over which the sea had broken, and killed all the worms—the field remained sterile until the worms again inhabited it. He also showed me a piece of pasture-land near to his house in which worms were in such numbers that he thought their casts interfered too much with its produce, which induced him to have the field rolled at night in order to destroy the worms. The result was that the fertility of the field greatly declined, nor was it restored until they had recruited their numbers, which was aided by collecting and transporting multitudes of worms from other fields.

The great depths into which worms will bore, and from which they push up fine fertile soil, and cast it on the surface, has been admirably traced by Mr. C. Darwin, of Down, Kent, who has shown that, in a few years, they have actually elevated the surface of fields by a layer of fine mould several inches thick, thus adding to the pabulum of the grasses. His experiments were made at Mr. Wedgwood's, of Etruria, and are recorded in the 'Gardener's Chronicle' of April 6, 1844. Mr. Darwin's researches are entitled to the strictest credibility. Here are some specimens of warp soil now undergoing drainage by me on an estate of Mr. William Marshall's, M.P., near Patrington, fourteen miles east of Hull, and opposite the well-known tract of land, reclaimed likewise from the Humber, called Sunk Island. When first examining this soil for drainage, I was struck with the astonishing number of fine vertical holes penetrating the warp to its full depth, in some places 8 to 10 feet. These holes were evidently not the work of earth-worms, being of a much smaller bore, and worms abound in that soil, and were at work in their own fashion, though no other living creature was discernible. Very many of these minute holes seem to be fully appropriated by the fine roots of plants, which descend into them, and thus find easy access to moisture and air.

On further investigating into the origin of this net-work of holes, it was traceable beyond a doubt to the existence and activity of myriads of small marine animals, having numerous legs, and minute eel-like looking fish, working in the mud of recent deposition. The tidal stream from the Humber, which is conducted upon the warping grounds, and let out again with a retiring tide after the deposition of its solid matter, does not destroy the life of these creatures, nor close their cylindrical habitations. On the retirement of the water they are to be seen ceaselessly occupied in working up and down their holes further to maintain and elaborate them against the next invasion. The death of these amphibious animals no doubt occurs when the process of warping terminates, and the soil solidifies, but their holes remain entire and open from the top to the bottom of the mass, serving to admit air and moisture, and to pass the water of rain in finely divided streamlets to the drains, and the earth-worm finally establishes himself in a soil easily penetrated and most congenial to his mining habits. In the field of warp first begun to be drained on this estate, I have set out the drains at about 40 feet asunder, their depth varying from 4 to 6 feet, as outfall permits; but it is probable, as experience is gained of the draining faculty, that we may see fit to diminish the number of drains, and so increase their distance from each other in these soils. The alumina of the Humber warp is very fine and very retentive of moisture. Water appeared at 18 inches below the surface after a month of powerful evaporation and drought in May and June of this year, and copious streams were discharged from the deep drains. In its original state of wetness, but under circumstances of drought, this soil cracks widely and deeply like the stiffer clays, so that it seems to possess every facility for the most complete drainage, whilst its faculty for absorbing moisture from the air, and by capillary attraction from below, are of the highest order, which must vastly aid in conferring upon it the fertility well known to attach to warp lands.

But the quality of warp varies greatly, according as the deposit takes place in different parts of the same stream, and at greater or less distance from the warping river's mouth. I cannot perhaps mention a more remarkable instance of the difference in the properties of warp than what occurs at Bridgwater, in Somerset. The river Parrot is famed for the almost evergreen fatness of the pasturage bordering its banks, lands which were formed originally, it may be presumed, when that river was an estuary of the sea far inland. Its deposit immediately in the neighbourhood of Bridgwater has occasioned a great manufacture of very superior bricks and earthenware; and there is one article of almost universal domestic use, called the Bath brick, for cleaning knives, &c., made at Bridgwater only, and it is singular that the sludge or mud from which these bricks are made is collected from the river Parrot's banks, within about a mile above and a mile below the town of Bridgwater. The banks of those particular two miles of the river alone afford the precipitate fit for the manufacture of the Bath brick. The deposit formed, whether more inland or more seaward, is found to be unfitted for the purpose. So, in the warped lands formed from the water of the Humber, whether passed immediately from that river, the Ouse, or the Trent, great difference in the quality of the deposit and fertility of the soil in respect of the proportions of clay, sand, and salt is discernible and well known.

Great difference also exists as to the necessity of draining warped lands, arising from the depth of warp, the character of the subsoil on which the warp is run, and the particular composition of the warp itself in its proportions of clay and sand. Near to the mouth of the Humber it strikes me that there is a much larger proportion of alumina (clay) deposited, in respect of silica (sand), than about Goole, Thorn, and other warping districts. There is no doubt also much more common salt in the composition the nearer to the Humber mouth.

The quantity of salt in which the wheat-plant will flourish is curiously illustrated in the warp soils about Patrington, and would be scarcely credited unless seen. The whole surface of a large reclaimed warp-piece on Mr. Marshall's estate was planted with wheat for the first time in the autumn, 1844. When I saw it in the autumn of 1845, the surface of the ground was crystallized all over with salt, evidencing the enormous quantity which the mass of the bed must have contained; yet from this first crop the tenant told me he had threshed out 24 bushels per acre. The order of culture there, after warping, is to leave the land to the occupancy of what is called the sheep-grass, which naturally skins it for three years, when that begins to die off. It is then ploughed up, and sown with rape, allowed to go to seed. This plant is considered to remove the very injurious excess of salt, and great crops of it are obtained. Wheat follows, and, after that, any other crop of the farmer's liking, without regard to systematic rotation, may be produced, and without the aid of manure, for many years.

But the whole of this land is much too wet—it is too salt—and its powers will not be appreciable until after deep and complete under-draining. It appears, however, that the lands warped at a greater distance from the mouth of the river must be skilfully treated in respect of under-drainage. A complete power of deep under-drainage should be established to withdraw the water and keep it down low beneath the surface when injurious, whilst there should be provided means of sustaining water nearer to the surface and to the roots of plants, when under the influence of such a dry season as was experienced in 1844.

In many of these warped lands means exist to fulfil this end, as water is raised out of the ditches by machinery when in excess, and the height of water in the ditches is maintainable by drawing it from the high land drains. A farmer, residing near to Hatfield Chase, informed me that he considered he saved crops of the value of 1500*l.* in 1844 (when it will be remembered we had fourteen weeks of hot sun without a drop of rain), by his command of water to charge his ditches. The warped lands are very commonly divided into fields of 10 acres, being squares of 220 yards, surrounded by open ditches, and it is considered that the water is thoroughly drawn out of the soil to the level maintained in the ditches; but this I much doubt, and am satisfied, from my observation of these flat warped lands, both in wet and dry weather, that they would be astonishingly benefited by a system combining both sub-drainage and sub-irrigation; but it is possible that the farmer may have reason for not draining this soil more deeply or more completely, unless means are provided for sub-irrigation in droughty seasons.

There has been rather recently introduced by some drainers a practice of making what they term air-drains, with the view of providing for a ventilation of the soil, and also for promoting, as they think, a freer flow of water from drains. As regards the latter point, it is quite certain that such air-drains must be superfluous and unnecessary. The fact of water entering subterranean drains at all is quite decisive as to the universal presence of air in soil, and no one has shown or has attempted to show, so far as I know, its insufficiency. Water could no more issue from a drain laid in the earth, than it could flow from a tight barrel, if air did not press on the surface of the liquid within it. Every one knows how small a vent-hole at the top of a cask suffices to enable us to withdraw a great stream from it at the bottom, and every one knows that the bulk of liquid discharged in a given time is in quantity precisely equal to the volume of air which enters in the same time. The fact of rain-water sinking through the soil is demonstrative of the permeability of that soil to air, as every drop of water which falls from the heavens must first displace an equal volume of air before it can enter the soil; the water would remain on the surface and never sink if, by reason of its superior gravity, it did not push aside the air in its descent, which it does until it meets with some subterranean level where the earth is saturated with the fluid, and the rain-water then comes to rest, having disturbed and displaced air throughout its whole downward course. And by this action we are led to observe one beautiful provision of Nature for renewing the constituent air of the soil—and I regard it as an argument in favour of deep, as compared with shallow drainage—that a greater bulk of earth is thereby filled with air, and with frequently renewed air.

There are other equally beautiful processes incessantly active to maintain a full supply, and fresh supplies, of air in the soil. The continual change of temperature in the soil and in the atmosphere reposing upon it has its effect; but probably the most potent cause is the unceasing appropriation by plants, or manures, or soil, of some one or other of the three gases of which the atmosphere is composed. A renewal of the particular atmospheric gas consumed, whether it be oxygen, nitrogen, or carbonic acid, must be nearly consentaneous with its use, and is effected by the well-known principle of the diffusion of gases, and without which neither plants nor animals could live.

I have spoken of cesspools a useful and convenient breaks in lines of drains, particularly in the long run of a main, or where several lines of drains converge from two or more directions in one common central point to an outfall. The use of the cesspool in drainage is an old English practice; I have found it in several counties, both North, South, and Midland: it is usually constructed in brick. The specimens now exhibited are made of large earthenware pipes 9 inches in diameter, with a flat tile or foot on which to place them in the soil. This plan will be found advantageous and cheap, as the foreman drainer may fix his cesspools without needing bricks and mortar and a bricklayer. The holes for the receiving-pipes are burnt in these cesspools of the proper dimensions, and the hole for the discharging or outfall-pipe is made a little lower than the holes of the receiving-pipes, so that a drip or fall from the former takes place, and the run of water from each pipe is observable. I have converted these cesspools to another use, viz. that of enabling us to introduce water into the body of the earth, and apply it to what I have before termed sub-irrigation. All the drains of a flat field may be made to issue from a cesspool, into which water from a higher level may be conducted. A cesspool of the same kind is also to be fixed at the outfall end of that field, into which all the drains are conducted. Now, by stopping up the outfall-pipe, and letting water into the infall cesspool, it is clear that all the pipes ramifying through a field will become filled with water, and that they will disseminate it gradually throughout the entire mass of earth above the level of the drain-pipes, and to any desirable height, as you will observe from the specimens before you that an outlet-pipe can be formed in the discharging cesspool at any required distance below the surface of the soil, or at the surface. In this manner water may be given to the roots of plants—I refer more particularly to the grasses; and when enough is given, the whole of the water may be removed at will, and a perfect drainage be established. The introduction of these cesspools with pipes also enables us to fill the higher parts of a field with water, which, suddenly liberated, will scour out the lower drains, and prove their condition of openness. The cesspool is also useful when placed close to an outfall into a stream or ditch, in which the water backs up with floods. It may then be furnished with a pipe and valve, here shown, which closes against the rising of the outfall water, and opens as the flood water falls, letting out the drainage water. By these simple means the sedimentary flood water is prevented from entering the drain-pipes, which remain filled with the clear water of drainage. In case of need, the receiving and discharging pipes may be luted into the cesspools with Jeffery's marine glue, but, in most cases, a ramming round with clay will suffice for the purpose, absolute tightness being rarely necessary.

These cesspools, with the various pipes now exhibited, have been made for me by Mr. J. M. Hoskison, of Wilnecote, near Fazeley, Staffordshire. They are admirable specimens of manufacture for truth and smoothness.

It will be observed that I have not introduced to your notice any other kind of drain-tile than pipes, and because I consider them to have the preference over every other description of drain-tiles, and for the following reasons:—

1st. Because the pipe is an entire conduit in itself, stronger than any other form, and capable of being centred and connected by collars, or of having one pipe sheathed within another.

2nd. Because the pipe requires less substance of material for a given strength than any other form into which clay can be put.

3rd. Because the carriage is lighter both to the field and in the field: a great convenience and economy to the farmer and the drainer.

4th. Because, from their form, when properly laid in the soil, pipes are subject to less derangement from external pressure, or the entrance of earth or vermin, than other forms of drain-tile heretofore in use.

5th. Because a less amount of earth has to be excavated in forming a bed for the cylindrical pipe at a given depth, than for the common tile and sole.

6th. Because pipes can be laid truly and firmly on their bed, whether plain or with collars, without requiring the workman to stand in the drain.

Much has been said and written about the porousness of